

RESTRICTED CIRCULATION

This paper is not an official document; it is for information only and must not be quoted in any printed publication.

Agricultural Memorandum No. 915

Probability curves of minimum temperatures below stated thresholds during spring in S.E. England

by C P Roe, Meteorological Office, MAFF, Reading

Introduction

An evaluation of the frost risk at a proposed orchard (or other) site is a necessary consideration during the planning stage of an enterprise where it is intended to grow high yielding, but invariably frost sensitive crops. A knowledge of the frost potential is also helpful in estimating the economic gains resulting from the use of frost protection equipment in both new and existing sites.

Horticultural experts have in recent years expressed interest in the effects of low temperatures on the pollination of fruit and it is hoped that the information presented here will fulfill some of the need for data in this field.

Probability curves of spring air temperatures less than or equal to seven thresholds, with an upper limit of 3°C , for 29 long-term met. stations are presented in alphabetical order in Figs. 1 - 29. Data for 1959-79 was used in most cases except where curves had already been drawn for the period 1959-77 during the course of advisory work; inclusion of 1978 - 79 data in these graphs was found to have no significant effect on the ogives and were therefore not included. It is hoped that combining this data with the mean dates of first and last frost given by Roe (1981) will enable a useful assessment of the potential frost risk to horticulture to be established.

Data for the other main fruit growing areas of England, namely East Anglia, the Vale of

Evesham and the South-west peninsula is also included for the sake of comparison (Figs 30 - 33).

Method

The period 1st April - 2nd June is considered and is divided into nine weekly intervals. Minimum temperatures $\leq 3^{\circ}\text{C}$ throughout the period for each year are attributed to the week in which they occurred. These figures are then combined for 1st April - 2nd June, 8th April - 2nd June 27th May - 2nd June (denoted by the letters A, B I respectively). The number of years in which one or more minimum temperatures $\leq 3^{\circ}\text{C}$, $\leq 2^{\circ}\text{C}$ $\leq -3^{\circ}\text{C}$ occurred during the periods A to I are noted and expressed as a years in ten figure. These frequencies are plotted on graph paper and "smoothed" to give the ogives shown. As an illustration of their use consider the curve for Goudhurst: temperatures $\leq 3^{\circ}\text{C}$ occur approximately 6 years in 10 during the period 27th May - 2nd June while temperatures $\leq 0^{\circ}\text{C}$ will occur, on average, once in 10 years.

Comments on the data

1. The curves can be used to determine the frost incidence at a given site. Briefly the method is as follows.

Minimum temperatures during April and May are recorded daily at a number of points over the area being surveyed. Normally one seasons readings are taken but several years of records will allow a better assessment of the frost frequency to be made. By comparison of daily minima at the orchard site with corresponding values from a nearby long-term met. site ("base" station) a mean temperature anomaly can be calculated. 'Weighting' the frequencies from the met site with this difference will give the frequency curves applicable to the orchard site.

Sims (1975b) illustrates that this technique is only justified if the weighting factor is determined from observations taken on radiation

nights when the long-term distribution curves of minimum temperatures will be of closely similar shape at the two places being compared. Thus there is likely to be an error involved if these curves, calculated from minima on all nights, are employed in a frost frequency analysis.

To determine the extent of the error involved frequency curves similar to those in Fig 1 were plotted for Gatwick and Manston for the period 1971-79. The analysis was then repeated omitting low temperatures occurring on nights other than 'radiation nights' (determined by reference to hourly values of temperature, wind speed and direction and cloud amounts during the time of dry-bulb temperature $\leq 3^{\circ}\text{C}$). In both cases it was found that curves drawn for "radiation" nights and "all" nights were similar suggesting that it is practical to use these curves provided the weighting factor has been calculated from observations on radiation nights. It is estimated that the error introduced by smoothing the frequencies will be less than 1 year in 10 at any temperature level in most cases.

2. The curves were drawn from temperatures recorded at a height of 1.25 m above short grass which may be considerably warmer than at crop level (say 0.5m) on radiation nights. With clear skies (2/8 low and/or medium cloud) and minima $\leq 3^{\circ}\text{C}$, screen min - grass min (Δ) would probably be more than 2.5°C * and possibly as much as 5 to 6°C on nights with several degrees of (air) frost. Variations do occur, especially with light winds, but Δ will usually decrease as wind speed increases. The values of Δ on clear nights for Gatwick are shown below (after Pickup, 1980).

* Pickup showed that Δ based upon night minima and grass minima (recorded between 21 and 09 GMT) may sometimes be less than values of Δ experienced early in the night. This is because large Δ frequently occur shortly after sunset when there is a rapid fall of ground temperature.

Table 1

Depression (Δ) of grass-minimum temperature below screen -
minimum temperature on nights with less than 2/8 low
and/or medium cloud, 1961-69

Average overnight wind speed

	1 - 5 Knots				6 - 10 Knots				11 - 15 Knots			
	Mean	S.D.	n	SE of mean	Mean	S.D.	n	SE of mean	Mean	S.D.	n	SE of mean
Gatwick	3.29	1.09	137	0.09	4.04	1.21	39	0.19	2.87	0.51	7	0.19

S.D. = Standard deviation n = number of occasions SE = Standard error

Soil cover and soil type may also influence temperatures. From one year's results at Starcross, Devon, Gloyne (1953) showed that T_b (minimum temperature at $\frac{1}{4}$ " to $\frac{1}{2}$ " above bare soil) minus T_g (grass-min temperature) on radiation nights in April and May was 2.5°C on average, indicating that low temperatures will become less frequent as crop cover decreases. Night-time drops in surface temperature tend to be greatest over dry sandy soils and smallest over moist clay soils.

3. Most fruit crops can withstand some degree of frost without damage although this varies from crop to crop and even between different varieties. The temperature thresholds used in this survey were chosen to include a wide spectrum of needs. Cox's Orange Pippin apple is known to be susceptible to temperatures below -2°C , for example, while experience with blackcurrants has shown that a considerable loss of crop will result from minima $\leq -2^{\circ}\text{C}$ and partial loss from minima $\leq -1^{\circ}\text{C}$. (Davies, 1973) It is thought that low temperatures (not necessarily frost) may reduce the activity of pollinating insects and prevent the fertilisation of the ova during the flowering period, although the critical temperature thresholds are unknown (Partis, personal communication).

4. The method used in this analysis gives no indication of the number of frosts to be expected during April and May the assumption being that only one frost of the required severity after a given date is sufficient to damage or wipe out the crop (Sims, 1975a). Although an estimate of the number of years in 10 when this is likely to happen is a useful management input, a grower who contemplates frost protection by irrigation or heating will require an estimate of how often his equipment will be in use. The average number of days with air and ground frost for 16 sites in the South-east during April and May are given in Appendix 2.

Perhaps of more importance to the grower is an indication of the runs of days with air frost; a number of consecutive days with temperatures just above the critical level for the plant may prove more detrimental than a severe frost for one night. Runs of days with air frost for 4 stations are given in Appendix 3. At East Malling, for example, two consecutive nights with temperatures $\leq 0^{\circ}\text{C}$, $\leq -1^{\circ}\text{C}$ and $\leq -2^{\circ}\text{C}$ can be expected 4.2, 2.1 and < 0.5 years in 10 on average respectively during April; temperatures $\leq 0^{\circ}\text{C}$ on 3 consecutive nights are likely ~ 1 year in 10 during April and ~ 0.5 years in 10 during May.

Summary of data

Table 2 shows the probabilities of at least one air temperature below the given thresholds during the periods A, C, E and G for selected inland and coastal sites.

Table 2

Probability (years in 10) of at least one air temperature
given limits for selected sites in S.E. England

	A (1 APR - 2 JUN)							C (15 APR - 2 JUN)						
	≤3	≤2	≤1	≤0	≤-1	≤-2	≤-3	≤3	≤2	≤1	≤0	≤-1	≤-2	≤-3
GATWICK	10	10	10	10	10	8	5.5	10	10	10	9.4	8.4	6.0	2.7
WYE	10	10	10	8.5	6.7	4.0	1.8	10	10	9	7	4.6	2.0	0.7
MARGATE	6.8	5.2	3.0	1.1	<0.5	<0.5	<0.5	4.2	2.5	0.8	<0.5	<0.5	<0.5	<0.5
BEXHILL	10	8.6	7.1	5.2	3.0	1.0	<0.5	8.2	5.7	3.3	1.5	0.7	<0.5	<0.5
LITTLEHAMPTON	10	10	8.4	6.5	4.4	2.0	<0.5	9.0	7.6	5.0	2.5	1.0	<0.5	<0.5
GILLINGHAM	10	10	8.1	6.2	4.0	2.0	0.5	10	8.3	5.7	3.2	1.3	<0.5	<0.5
ALICE HOLT	10	10	10	9.5	8.0	5.5	3.6	10	10	9.8	8.5	6.2	3.4	1.8

	E (29 APR - 2 JUN)							G (13 MAY - 2 JUN)						
	≤3	≤2	≤1	≤0	≤-1	≤-2	≤-3	≤3	≤2	≤1	≤0	≤-1	≤-2	≤-3
GATWICK	10	9	8.3	7.3	5.5	3.4	1.6	9.5	7.6	4.7	2.3	1.1	0.5	<0.5
WYE	10	9	6.6	4.2	2.2	0.7	<0.5	7.4	4.5	2.7	1.2	<0.5	<0.5	<0.5
MARGATE	2.0	0.8	<0.5	<0.5	<0.5	<0.5	<0.5	1.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
BEXHILL	5.3	2.7	1.2	<0.5	<0.5	<0.5	<0.5	2.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
LITTLEHAMPTON	7.1	4.8	2.4	1.1	<0.5	<0.5	<0.5	2.2	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
GILLINGHAM	8.0	5.8	2.9	1.0	<0.5	<0.5	<0.5	10	8.3	5.7	3.2	1.3	<0.5	<0.5
ALICE HOLT	10	9.0	8.0	6.5	4.0	1.7	0.7	10	10	9.8	8.5	6.2	3.4	1.8

From Table 2 it can be seen that temperatures 0°C are likely 8 - 10 years in 10 after April 1st in inland areas while coastal sites experience such temperatures only 5 - 7 years in 10 after April 1st. After 29th April, these frequencies become 4 - 7 years in 10 in inland sites down to 1 year in 10 near to the coast.

Near to the coast, spring nights tend to be warmer than inland by as much as 2°C on average (Climatological mem.73) and this is particularly true at Margate where there is a much reduced risk of low temperatures compared to Wye, for example.

The enhanced frequencies of low temperatures at Gatwick and Goudhurst would indicate that these sites are in "frost hollows".

Acknowledgement

Mrs S Morris, CA for assisting in the analysis and Dr J Starr for his useful suggestions. Thanks also go to the computing section of Met O8a, Bracknell for running the necessary programs.

References

- Climatological memorandum 73. (1975). "Maps of mean and extreme temperature over the United Kingdom. 1941-70". Met. Office, London Road, Bracknell, Berks.
- Davies, J W (1973). "Estimating the frost risk for horticulture". Agricultural memorandum 533 (copies available from the Library, Met. Office, London Road, Bracknell, Berks)
- Gloyne, R W (1953) Met. Mag., Sept.
- Partis, J P Personal communication
- Pickup, M N (1980) "An investigation into the variations of grass-minimum depressions". Met Mag. No.1297; Vol.109, HMSO London.
- Roe, C P (1981) "Statistics of dates of last spring and first autumn air frost in South-east England". Agricultural Memorandum 914. (copies available from the Library, Met Office, London Road, Bracknell, Berks).

Sims, F P (1975a)

"Frost frequency in spring at Luddington EHS, with
general comments on the presentation of frost surveys"
Agricultural memorandum 731. (copies available from
the Library, Met Office, London Road, Bracknell, Berks).

Sims, F P (1975b)

"Frost surveys - a revised method of analysis".
Agricultural memorandum 757 (copies available from
the Library, Met Office, London Road, Bracknell, Berks)

Any comments or suggestions should be sent to the author.

APRIL 1981

Appendix 1

Station details

Station	Height a.s.l.(m)	Period of analysis if other than 1959 - 79	N.G.R.		Missing data month/year
			East	North	
ALICE HOLT	115		4805	1427	
AYLESBURY	96		4841	2115	
BEXHILL	4		5737	1072	
BOGNOR REGIS	7		4934	0989	
BRIGHTON	10		5313	1040	
BROGDALE (FAVERSHAM)	48	1959 - 77	6007	1593	
BROMLEY	65		5401	1691	
CHRISTCHURCH	4		4154	0938	
EASTBOURNE	7		5611	0980	
EAST MALLING	39	1959 - 77	5708	1571	
EVERTON	16		4302	0937	
FERNHURST	57		4908	1267	6/74
GATWICK	59		5265	1407	
GILLINGHAM	3		5785	1692	
GOUDHURST	85	1959 - 77	5722	1333	
HASTINGS	45		5809	1094	
HAYLING ISLAND	4		4716	0988	
HEATHROW	25		5077	1767	
HURLEY	43		4823	1829	
LECKFORD	117		4393	1362	
LITTLEHAMPTON	5		5033	1019	
LONG SUTTON	145		4749	1467	6/63
MANSTON	44	1961 - 77	6335	1666	
MARGATE	16		6368	1714	
MARTYR WORTHY	84		4517	1338	
NORTH HEATH	21	1969 - 77	5069	1227	
SHINFIELD	61	1959 - 77	4734	1686	
WISLEY	32		5063	1583	4/72
WYE	56	1959 - 77	6057	1469	
SANTON DOWNHAM	24		5813	2901	
STRATFORD-UPON-AVON	49		4164	2549	
PENZANCE	19		1469	0302	

Appendix 2

Average number of days with hail and ground frost

Station	Period	AIR		GROUND	
		April	May	April	May
ALICE HOLT	1961 - 70	4.0	0.7	12.9	6.0
AYLESBURY	1961 - 70	4.4	0.8	11.3	5.1
BEXHILL	1963 - 72	1.6	0.1	4.9	0.3
BRIGHTON	1963 - 72	0.6	0.1	7.4	0.5
EAST MALLING	1963 - 72	3.6	0.6	8.7	1.6
EVERTON	1961 - 70	2.4	0.4	8.2	2.5
FAVERSHAM	1961 - 70	3.9	0.6	8.3	1.6
FERNHURST	1961 - 70	5.4	0.6	10.8	4.3
GATWICK	1963 - 72	6.0	0.7	12.5	5.7
GOUDHURST	1961 - 70	6.0	1.2	11.8	6.9
LITTLEHAMPTON	1961 - 70	1.6	0.1	NO DATA	
MARGATE	1961 - 70	0.1	0.0	1.5	0.2
MANSTON	1961 - 70	1.9	0.1	5.7	0.6
MARTYR WORTHY	1961 - 70	4.1	0.7	11.4	4.7
WISLEY	1963 - 72	3.6	0.2	12.6	4.9

Appendix 3

Average runs of days with temperatures below stated thresholds

during the period 1959-77 (expressed as years in 10)

Station	Threshold °C	Consecutive days						Max no of consecutive days	
		2 days		3 days		4 days		April	May
		April	May	April	May	April	May		
EAST MALLING	≤ 0	4.2	2.6	1.1	<0.5	<0.5	<0.5	8	2
	≤ -1	2.1	0.5	<0.5	<0.5	<0.5	<0.5	6	2
	≤ -2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	5	1
FAVERSHAM	≤ 0	3.7	2.1	2.1	<0.5	<0.5	<0.5	3	2
	≤ -1	1.6	0.5	0.5	<0.5	<0.5	<0.5	3	2
	≤ -2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3	1
GOUDHURST	≤ 0	2.6	2.6	1.6	0.5	1.1	<0.5	13	3
	≤ -1	1.6	2.6	2.1	<0.5	<0.5	<0.5	9	2
	≤ -2	3.2	0.5	<0.5	<0.5	<0.5	<0.5	9	2
WISLEY	≤ 0	2.6	0.5	1.6	<0.5	1.6	<0.5	8	2
	≤ -1	2.6	<0.5	1.1	<0.5	0.5	<0.5	4	1
	≤ -2	1.1	<0.5	1.1	<0.5	<0.5	<0.5	3	1

Fig. 1.

ALICE HOLT LODGE 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.

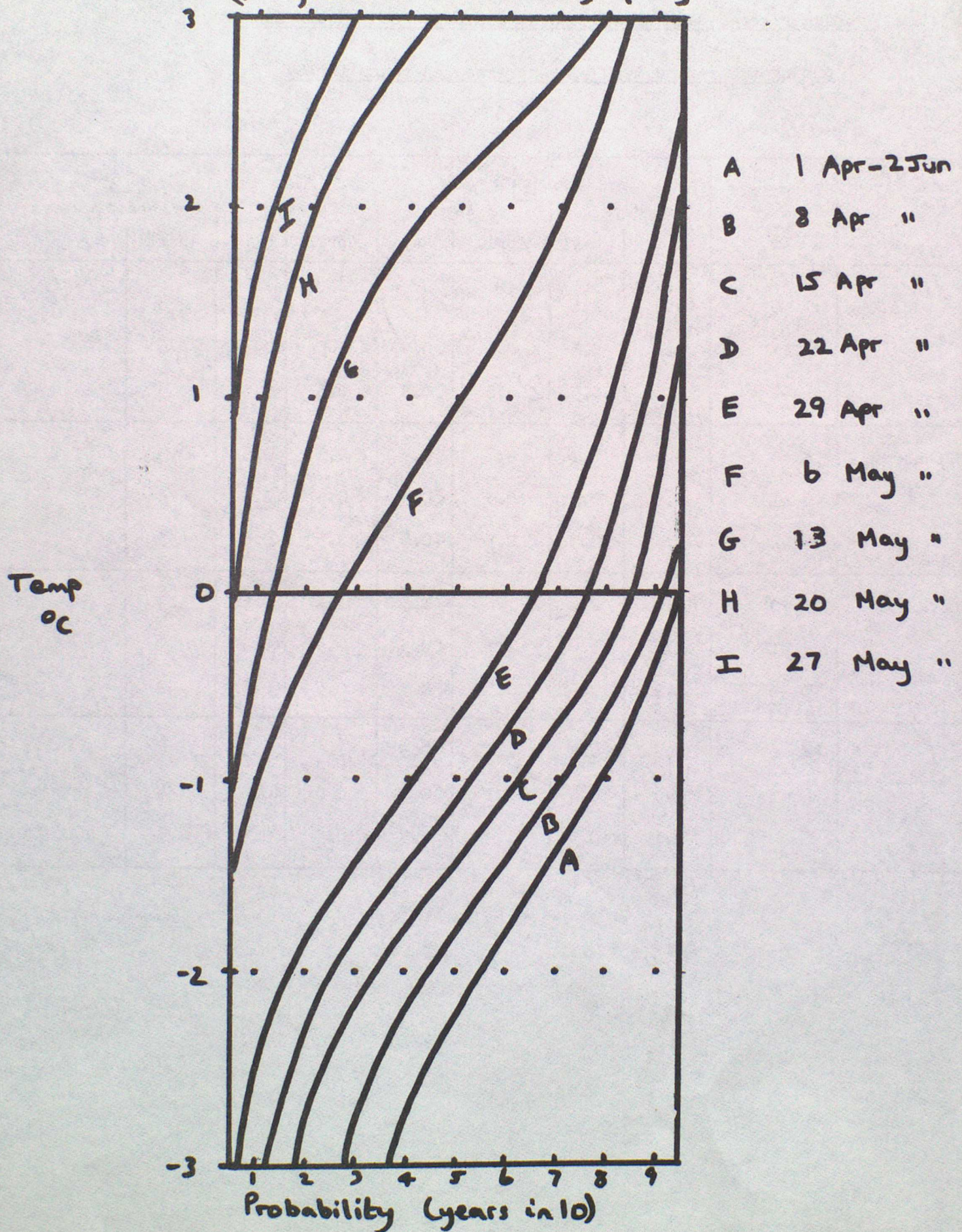
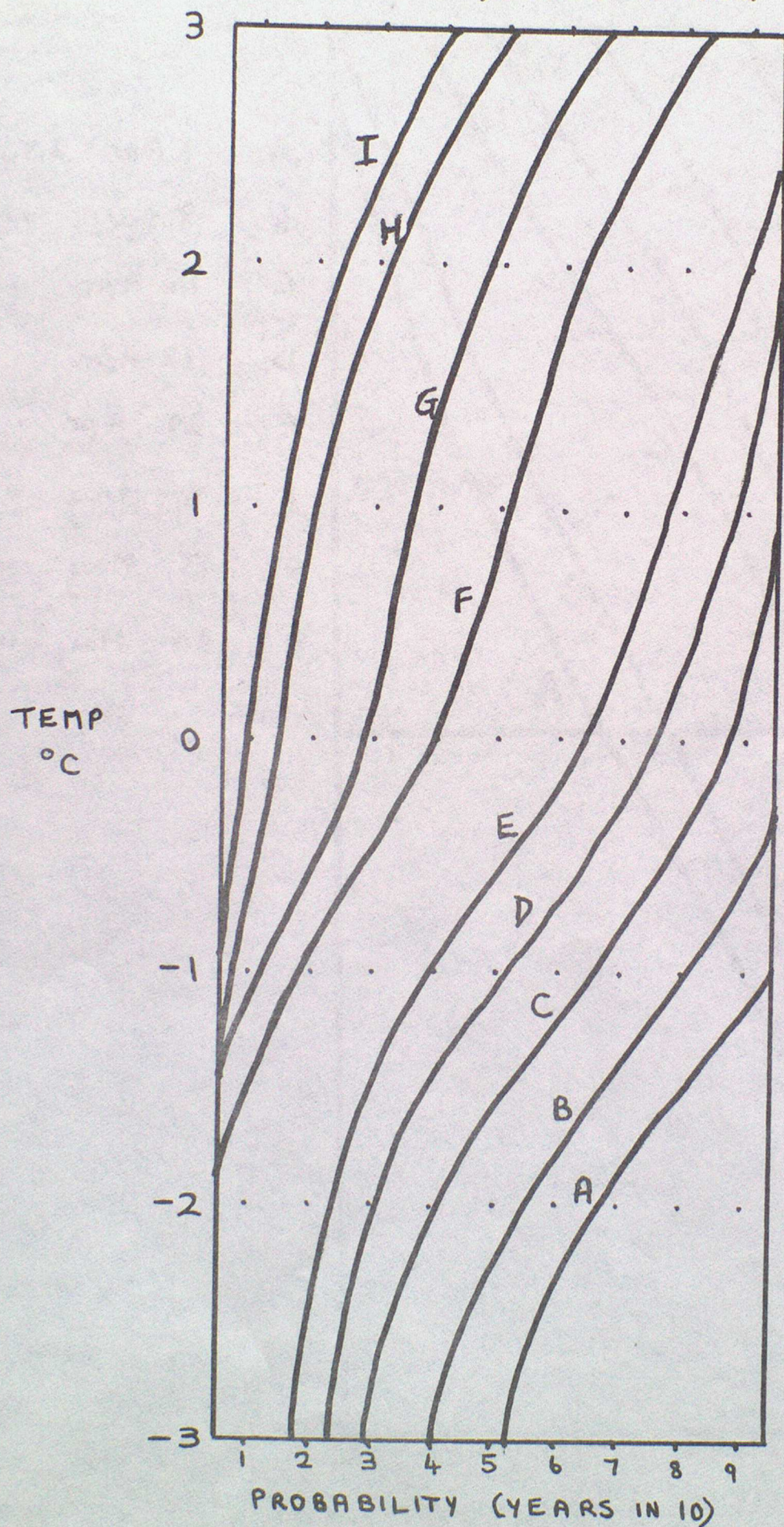


Fig. 2.

AYLESBURY (1959-79)

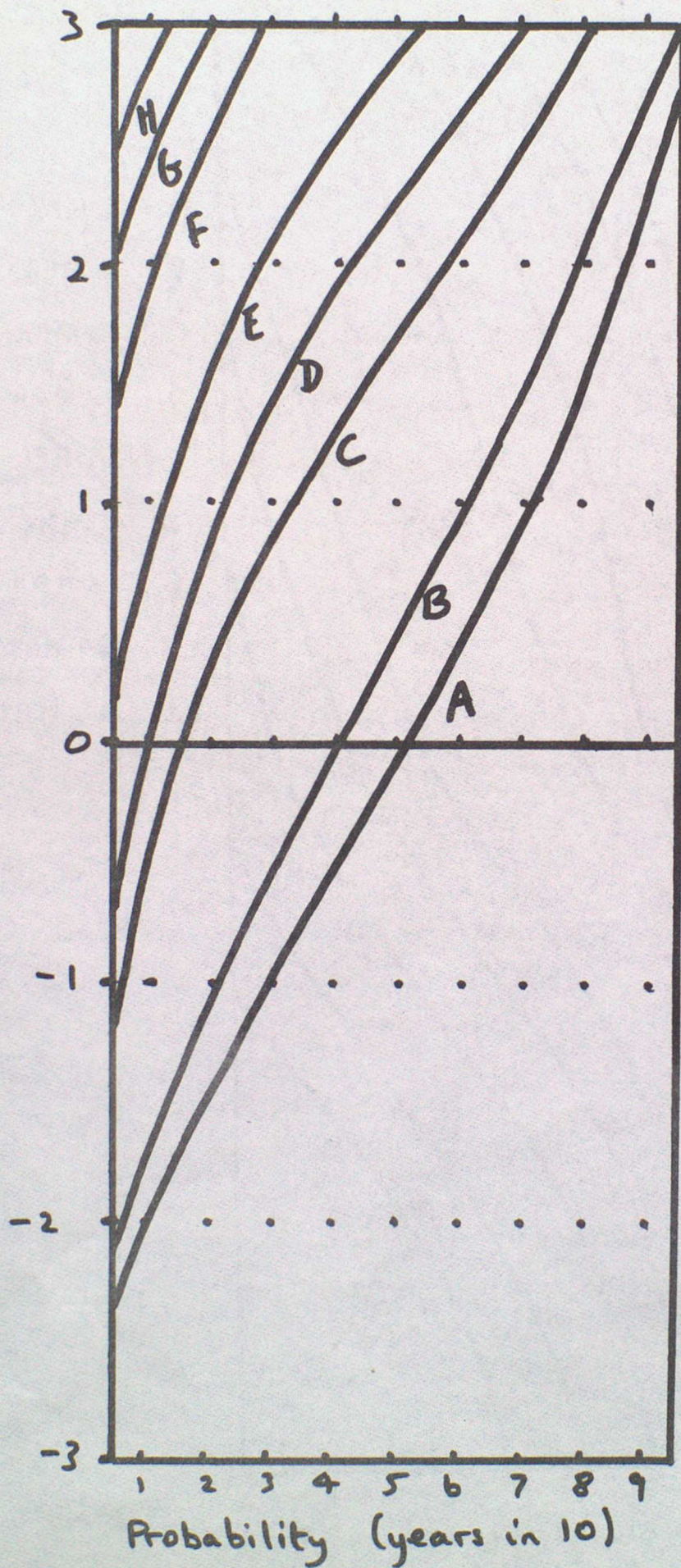
PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING

A	1 APR - 2 JUN
B	8 APR "
C	15 APR "
D	22 APR "
E	29 APR "
F	6 MAY "
G	13 MAY "
H	20 MAY "
I	27 MAY "

Fig 5.

BEXHILL 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring

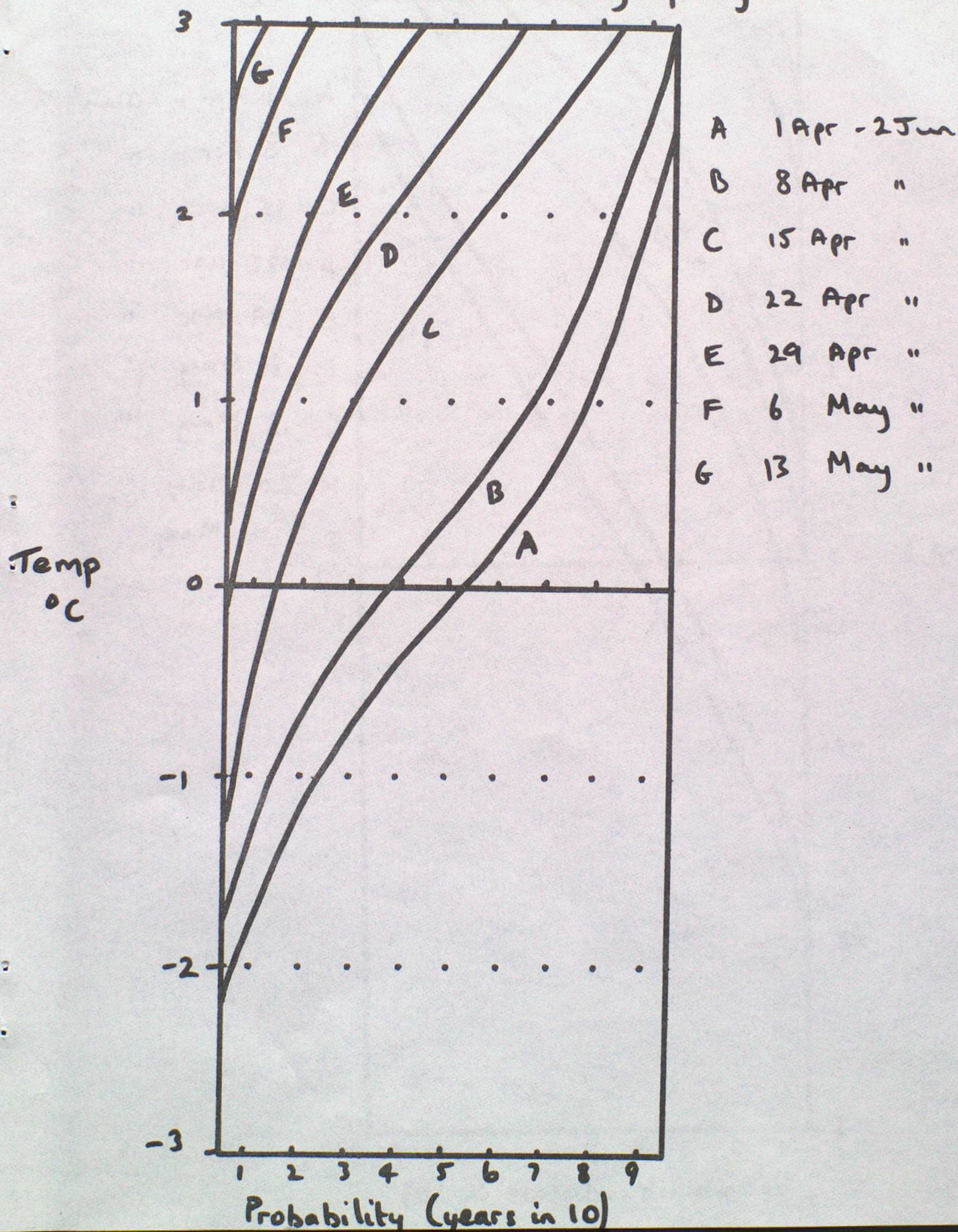


A	1 Apr - 25 Jun
B	8 Apr "
C	15 Apr "
D	22 Apr "
E	29 Apr "
F	6 May "
G	13 May "
H	20 May "

Fig. 4

BOGNOR REGIS 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



BRIGHTON 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.

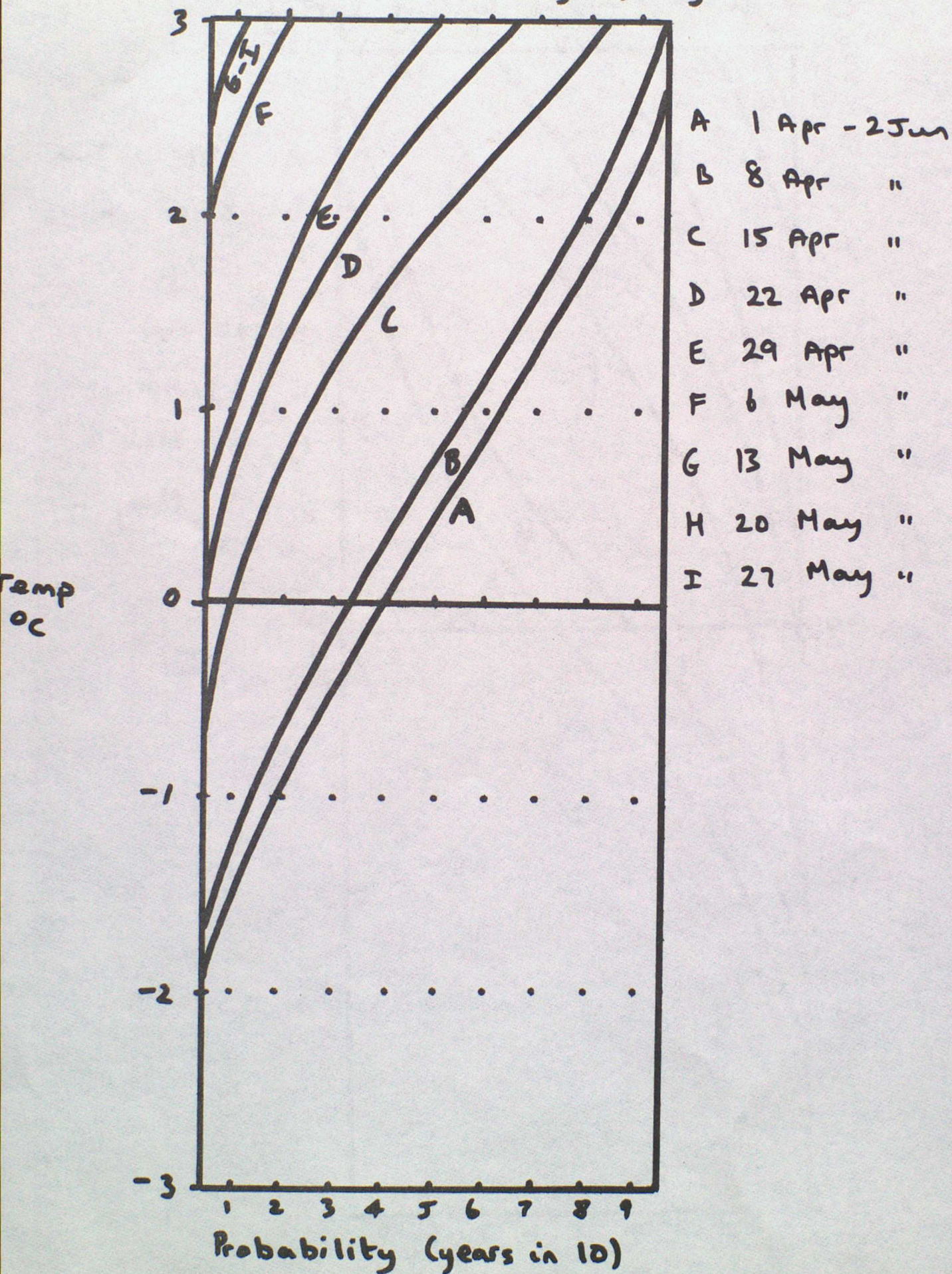


Fig. 6.

BROGDAL (1959-77)

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING

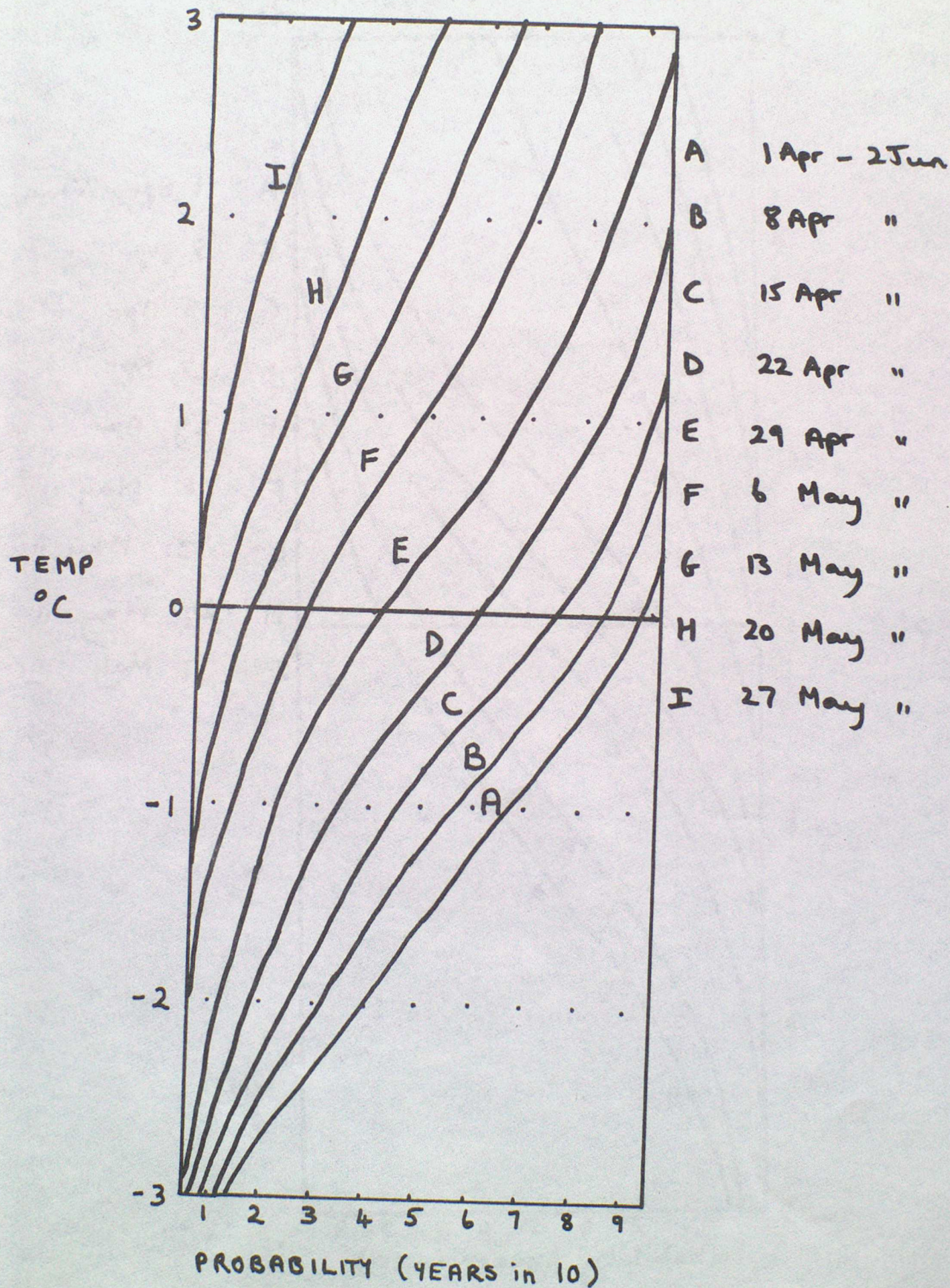
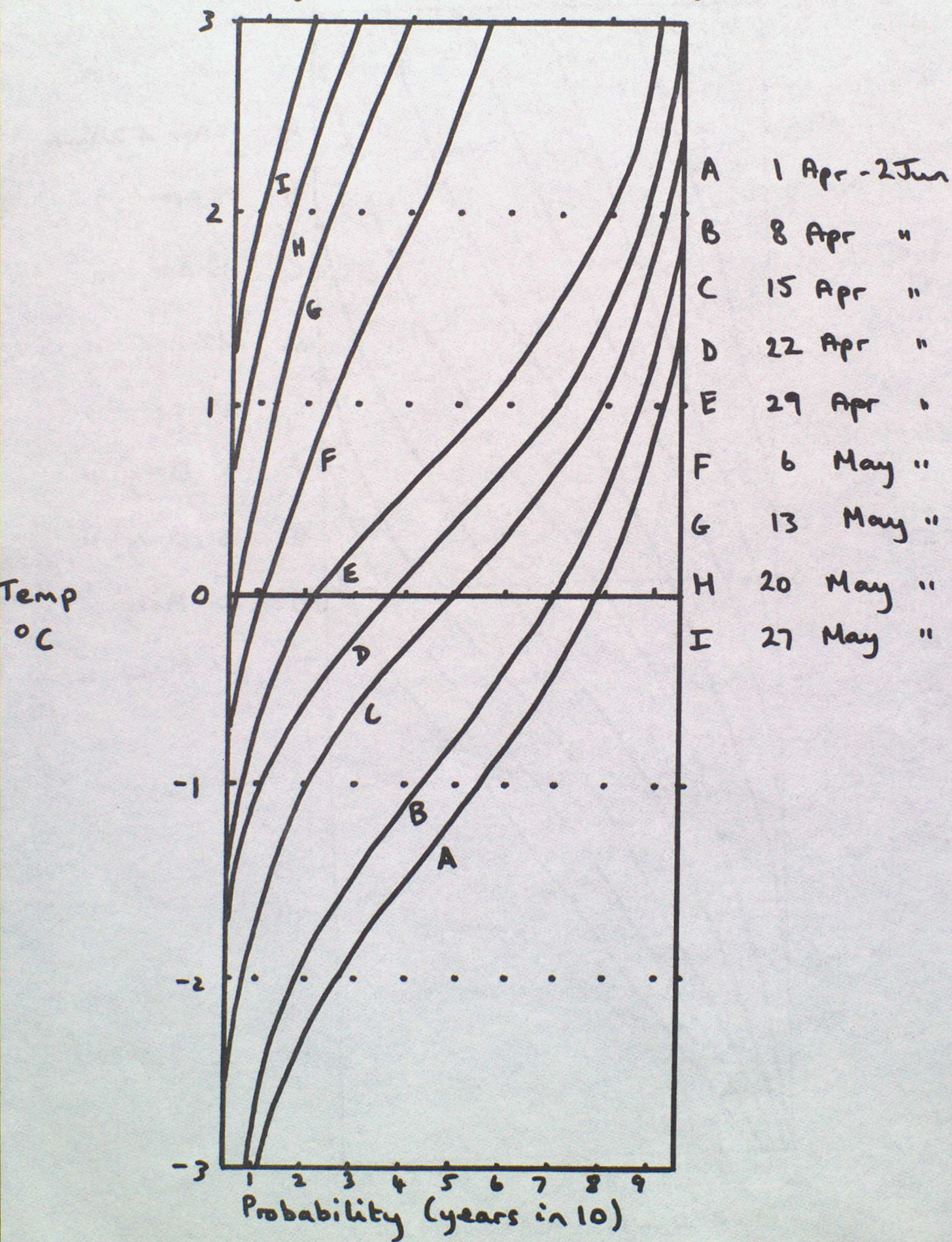


Fig. 7.

BROMLEY 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring



CHRISTCHURCH 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.

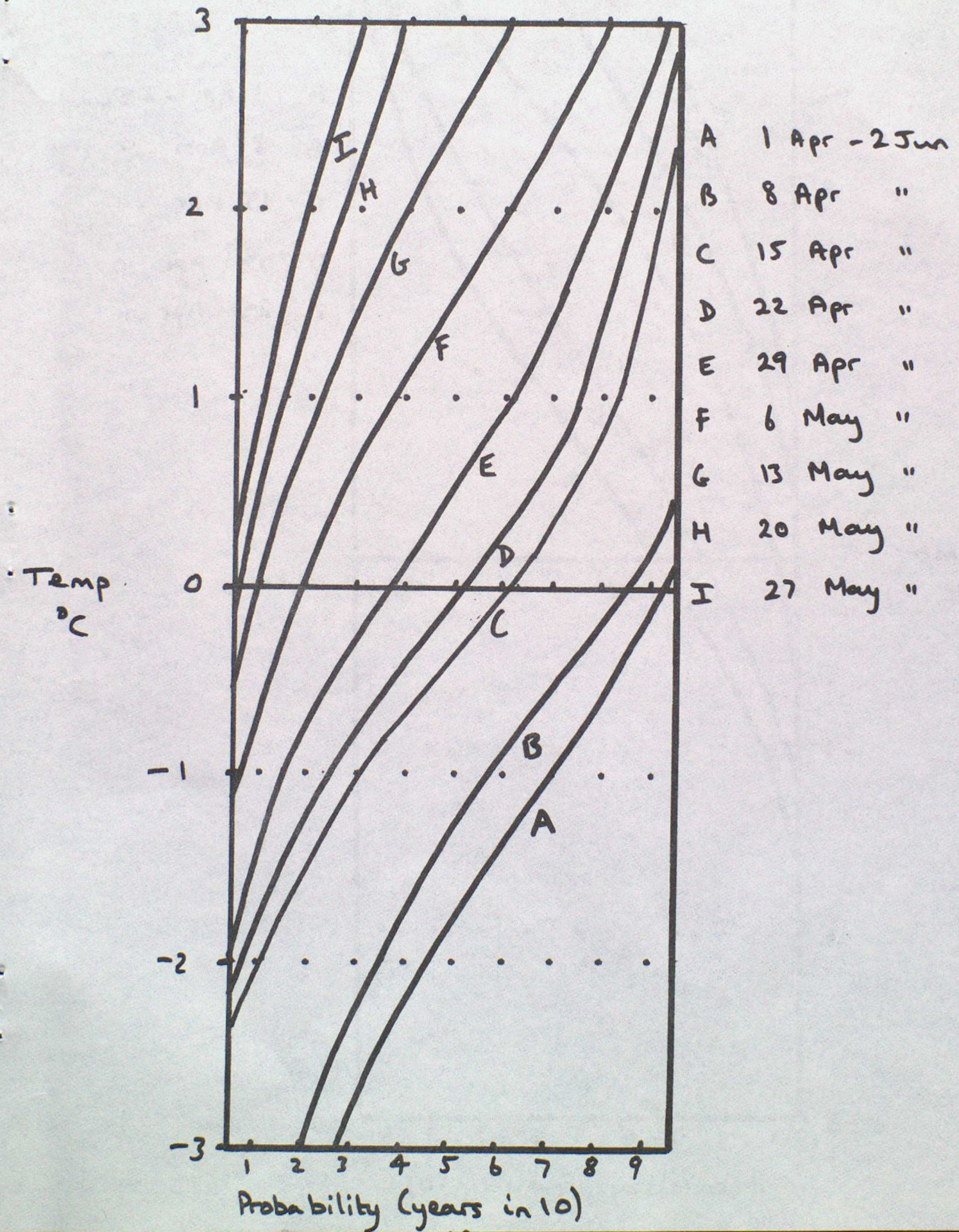
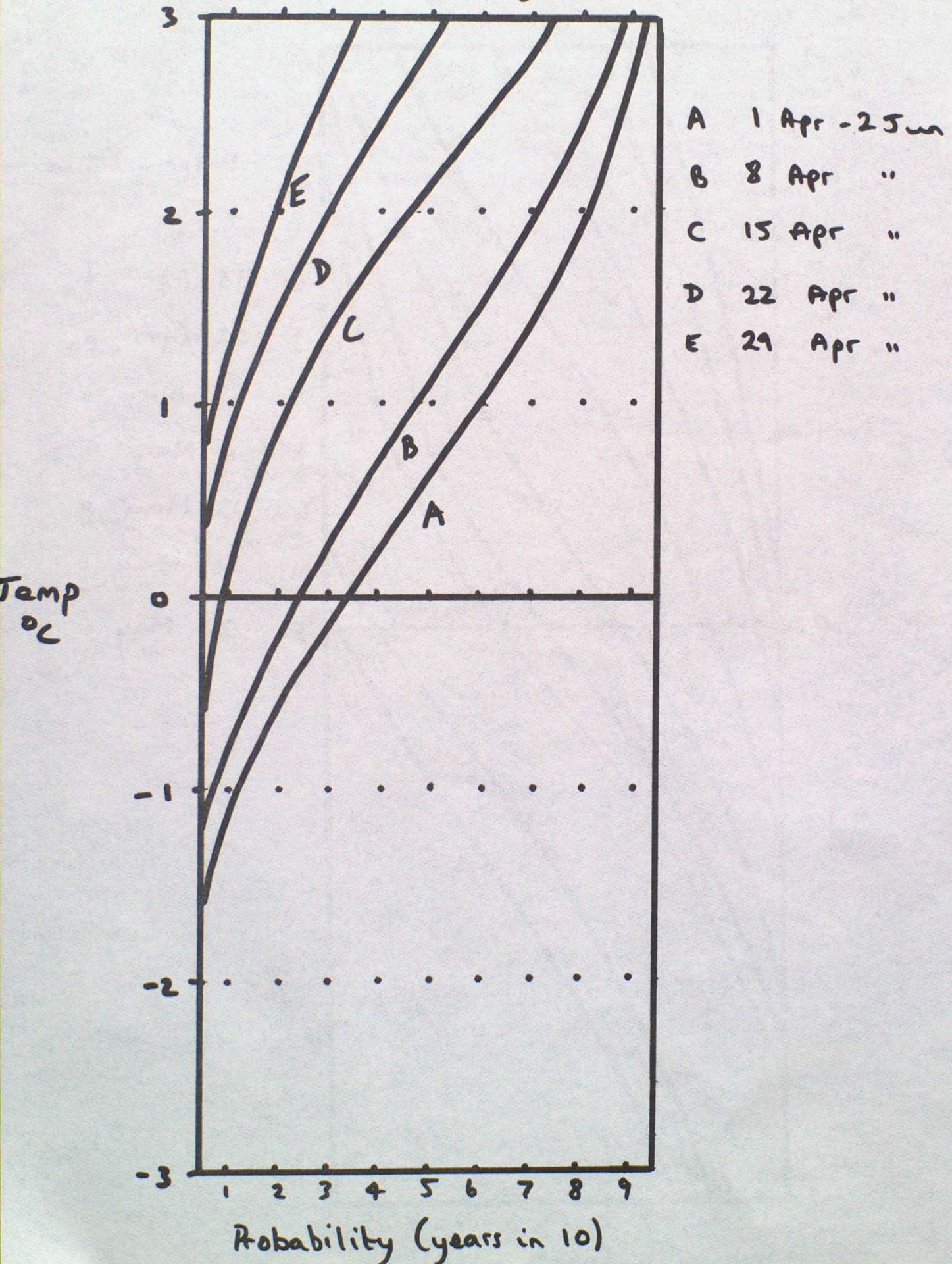


Fig. 9

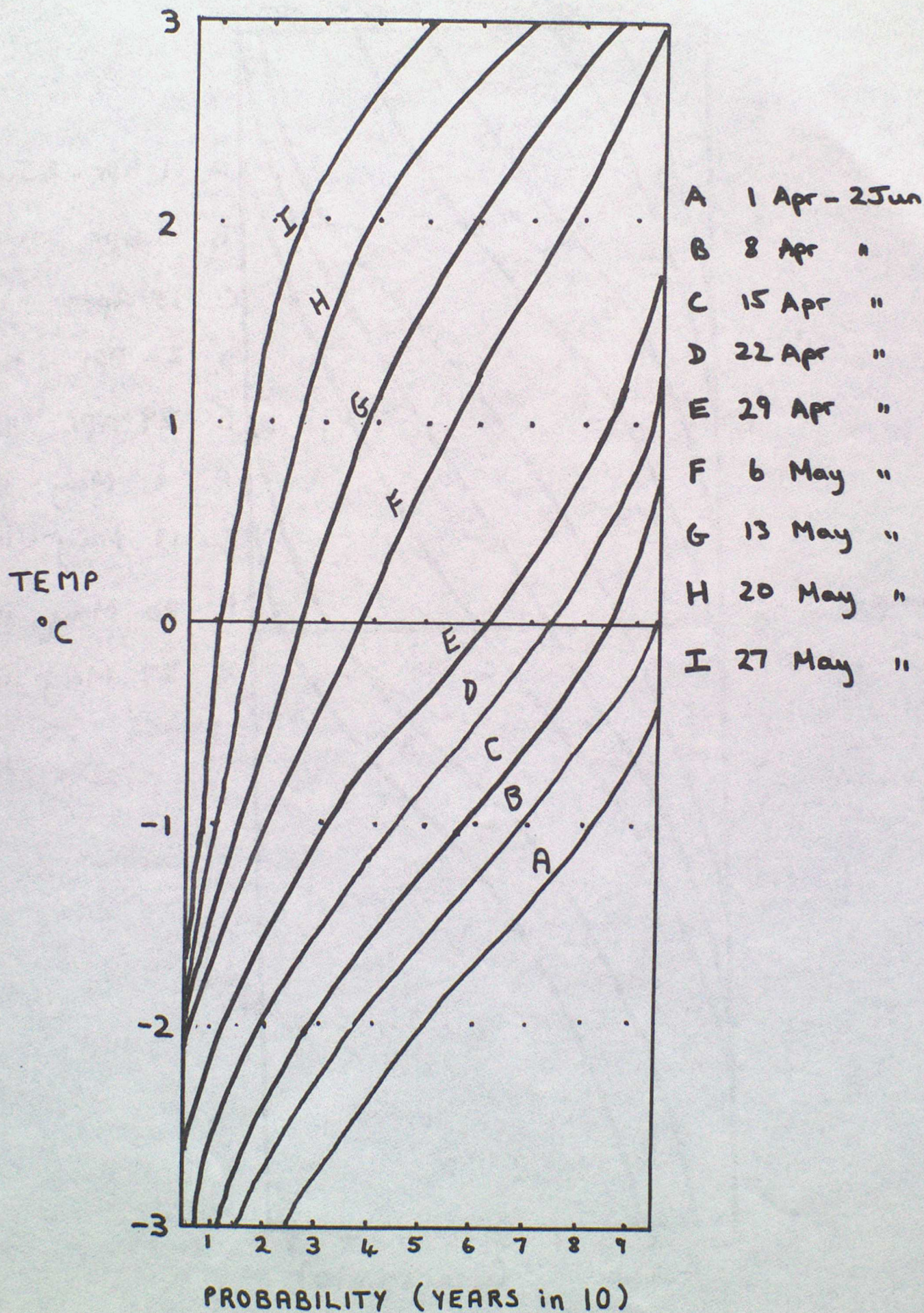
EASTBOURNE 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



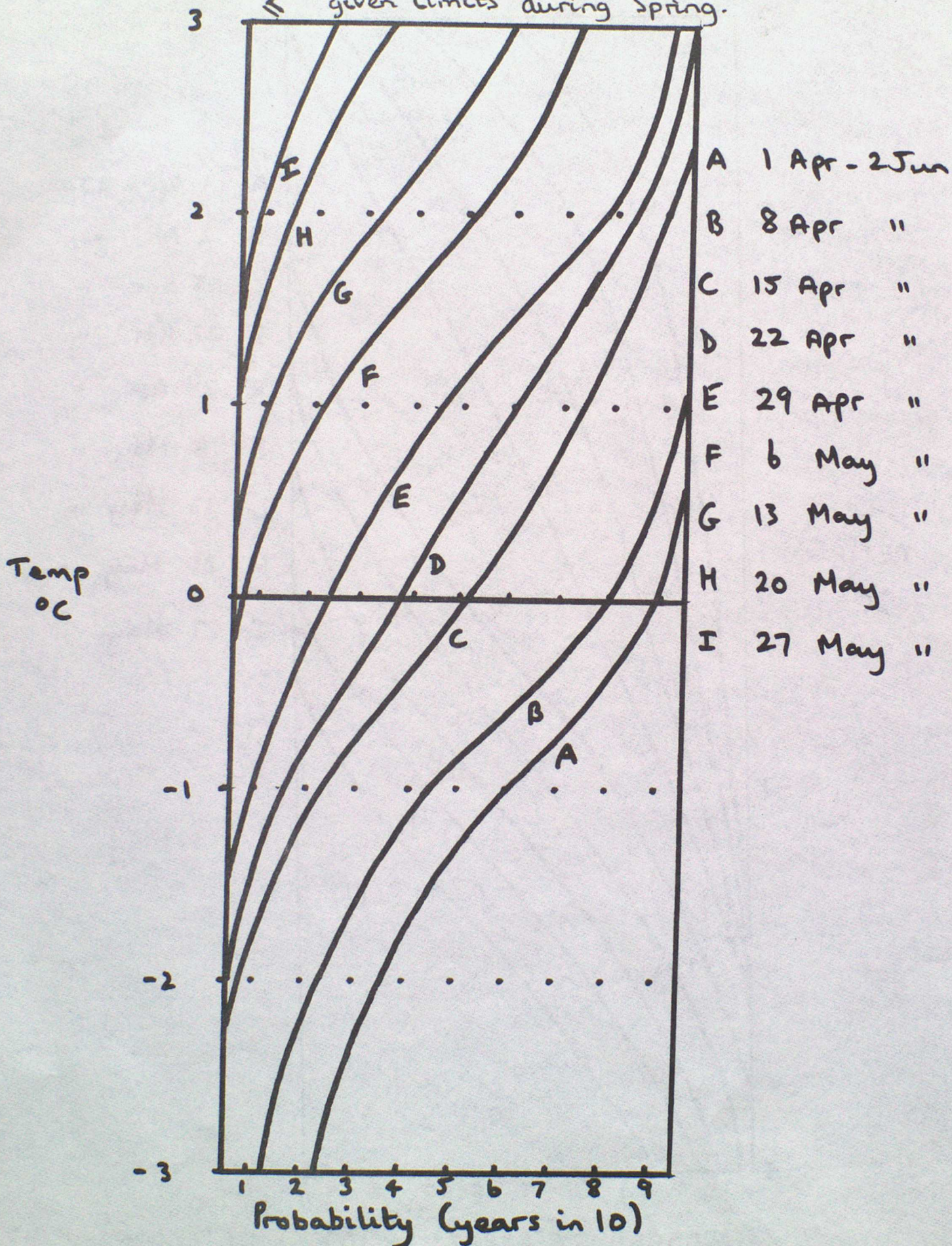
EAST MALLING 1959-77

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING



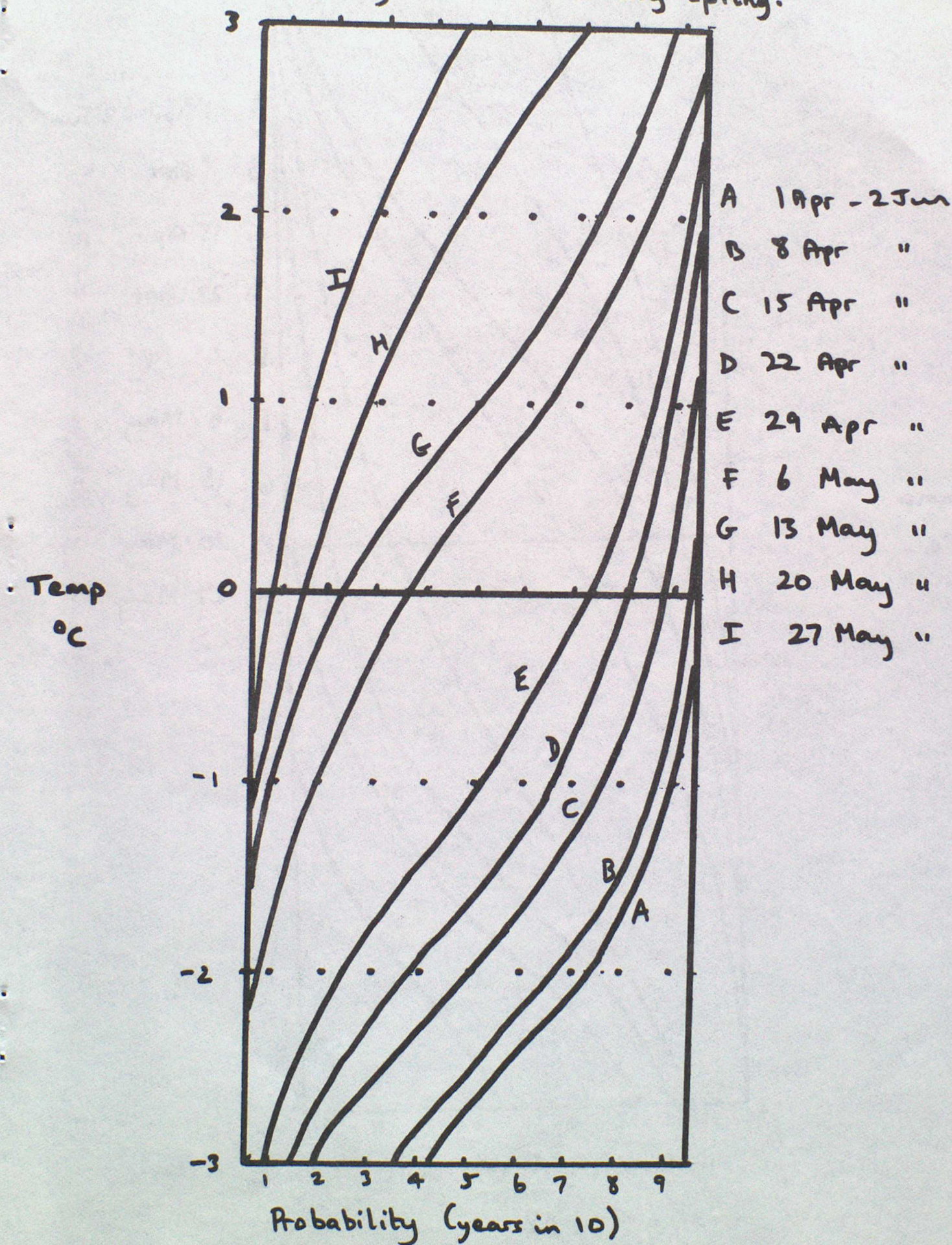
EVERTON 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



FERNHURST 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



GATWICK 1959-79

Fig. 13

Probability of at least one air temperature
 given limits during Spring.

Temp
 $^{\circ}\text{C}$

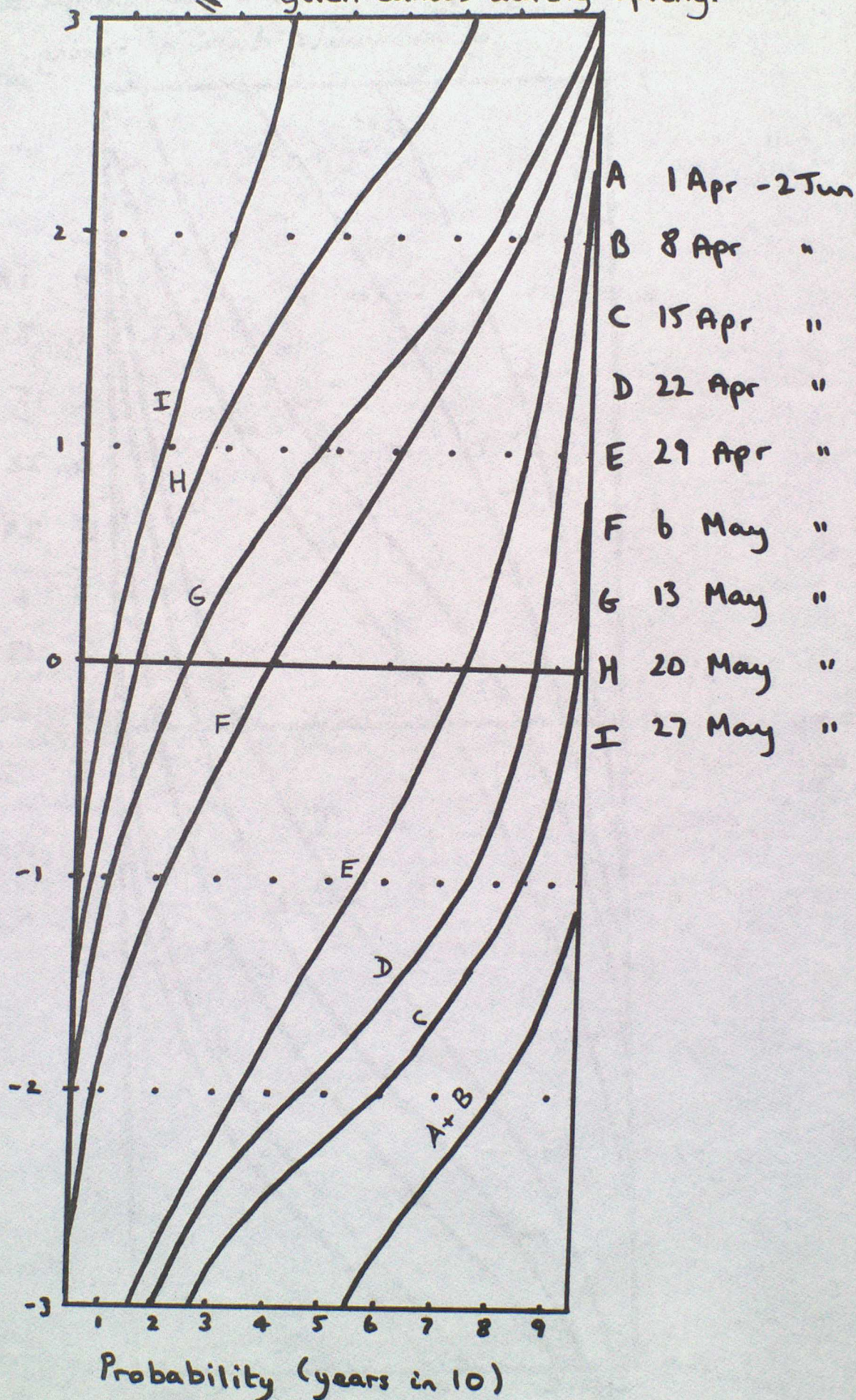
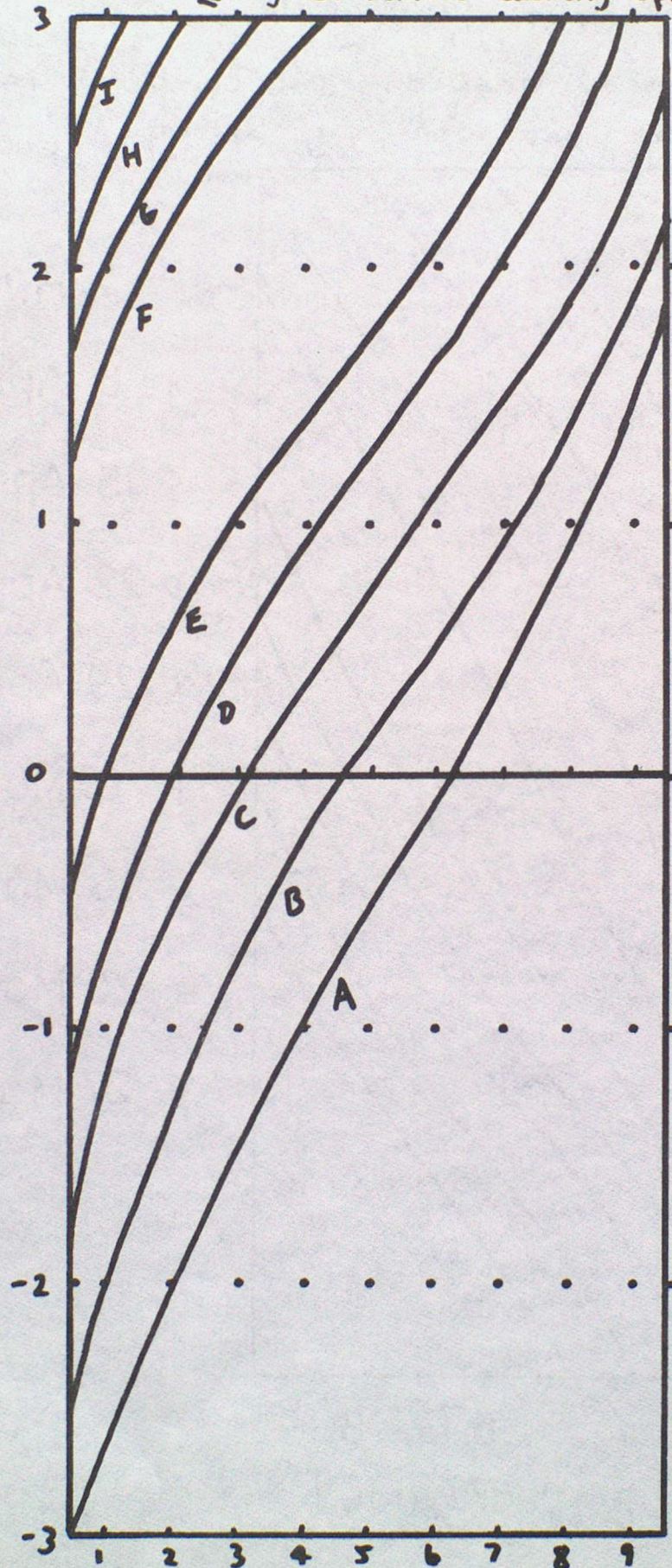


Fig. 14

GILLINGHAM 1959-79

Probability of at least one air temperature given limits during Spring.

Temp
°C



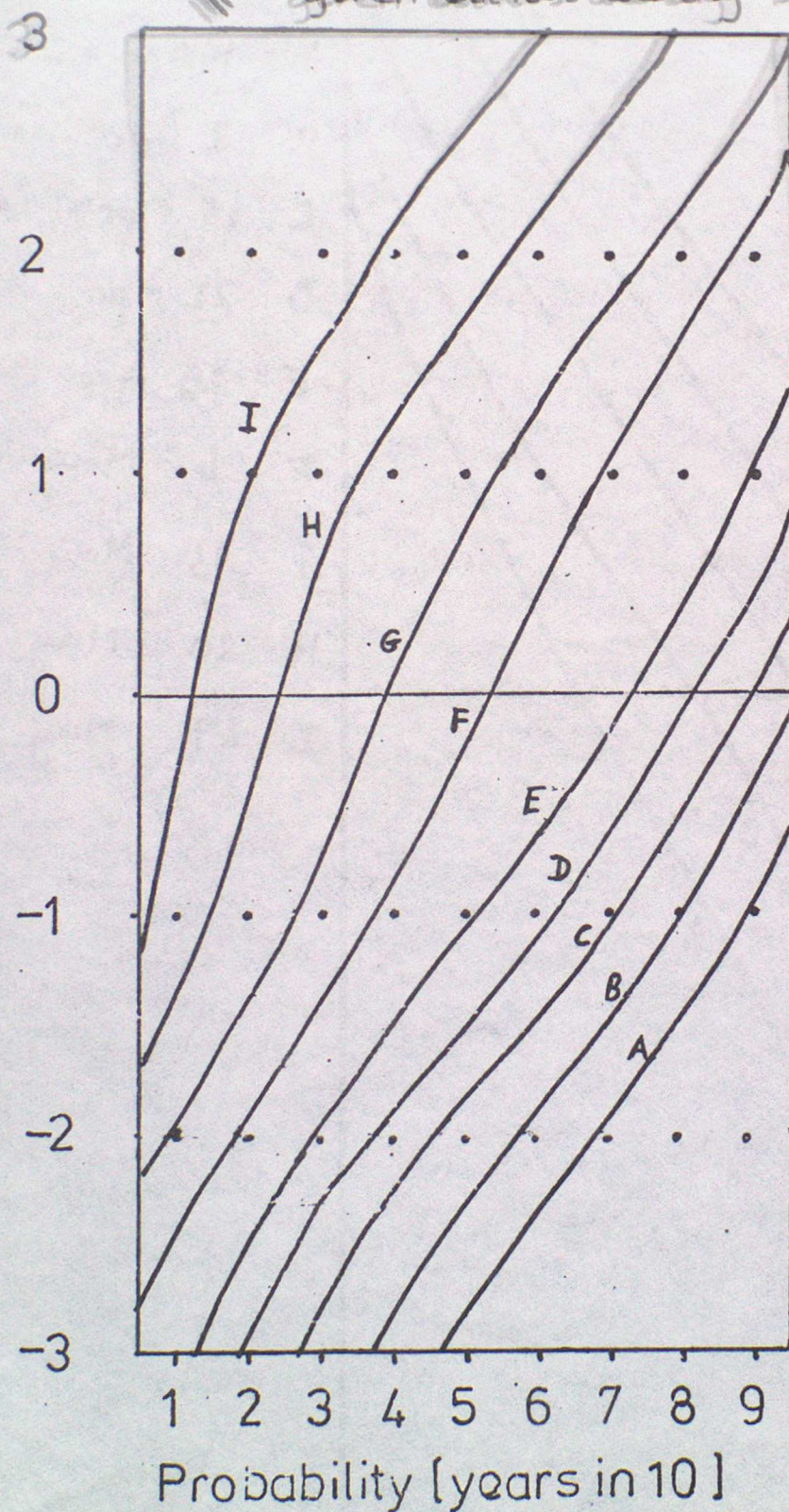
A	1 Apr - 2 Jun
B	8 Apr "
C	15 Apr "
D	22 Apr "
E	29 Apr "
F	6 May "
G	13 May "
H	20 May "
I	27 May "

Probability (years in 10)

Fig. 15

Goudhurst 11959-777

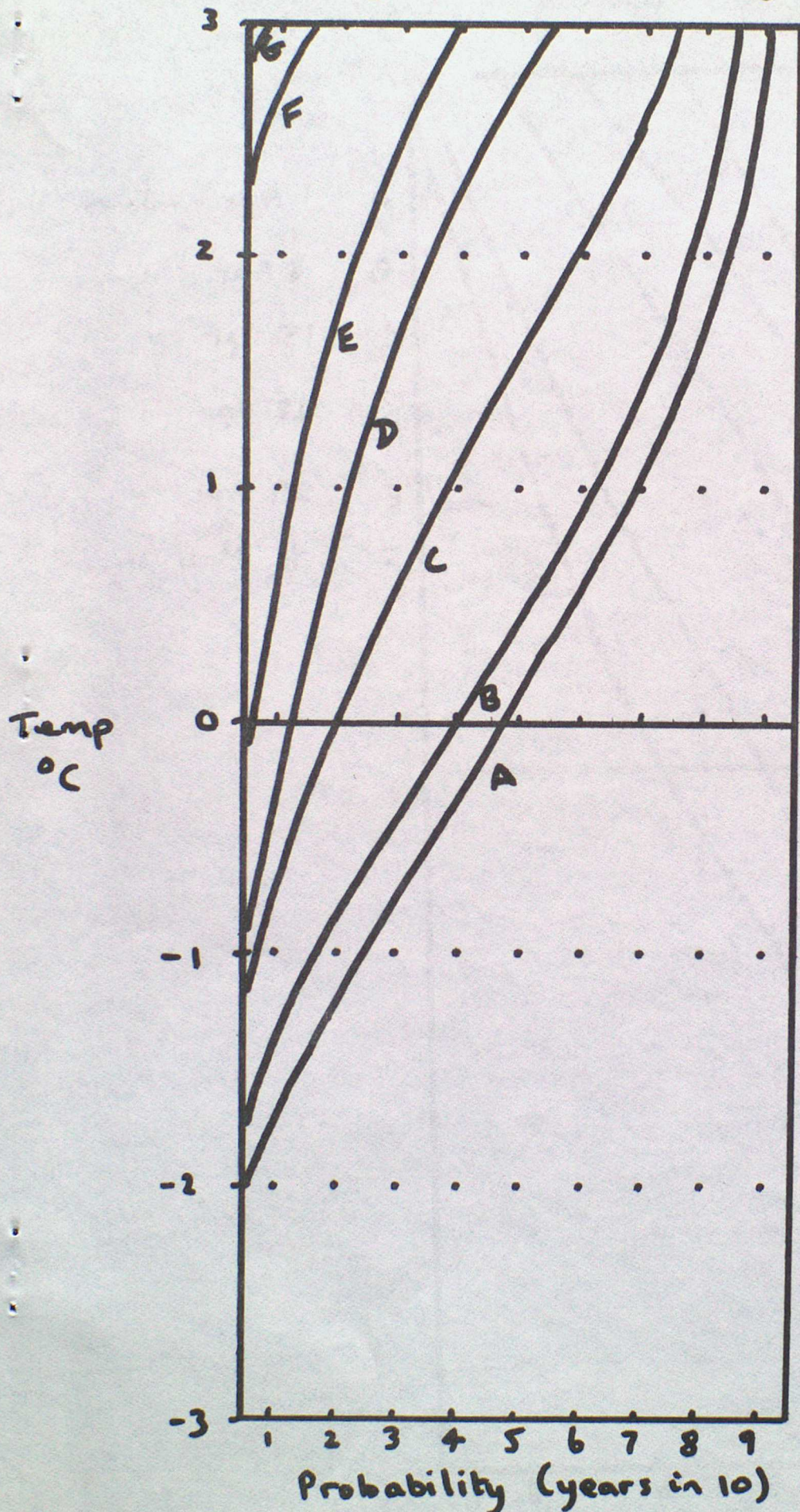
Probability of at least one air temperature
 given limits during Spring



- A 1 Apr - 2 June
 B 8 Apr "
 C 15 Apr "
 D 22 Apr "
 E 29 Apr "
 F 6 May "
 G 13 May "
 H 20 May "
 I 27 May - 2 June

HASTINGS 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



A	1 Apr - 2 Jun
B	8 Apr "
C	15 Apr "
D	22 Apr "
E	29 Apr "
F	6 May "
G	13 May "

HAYLING ISLAND 1959-79 Fig. 17

Probability of at least one air temperature
 $\leq$ given limits during Spring.

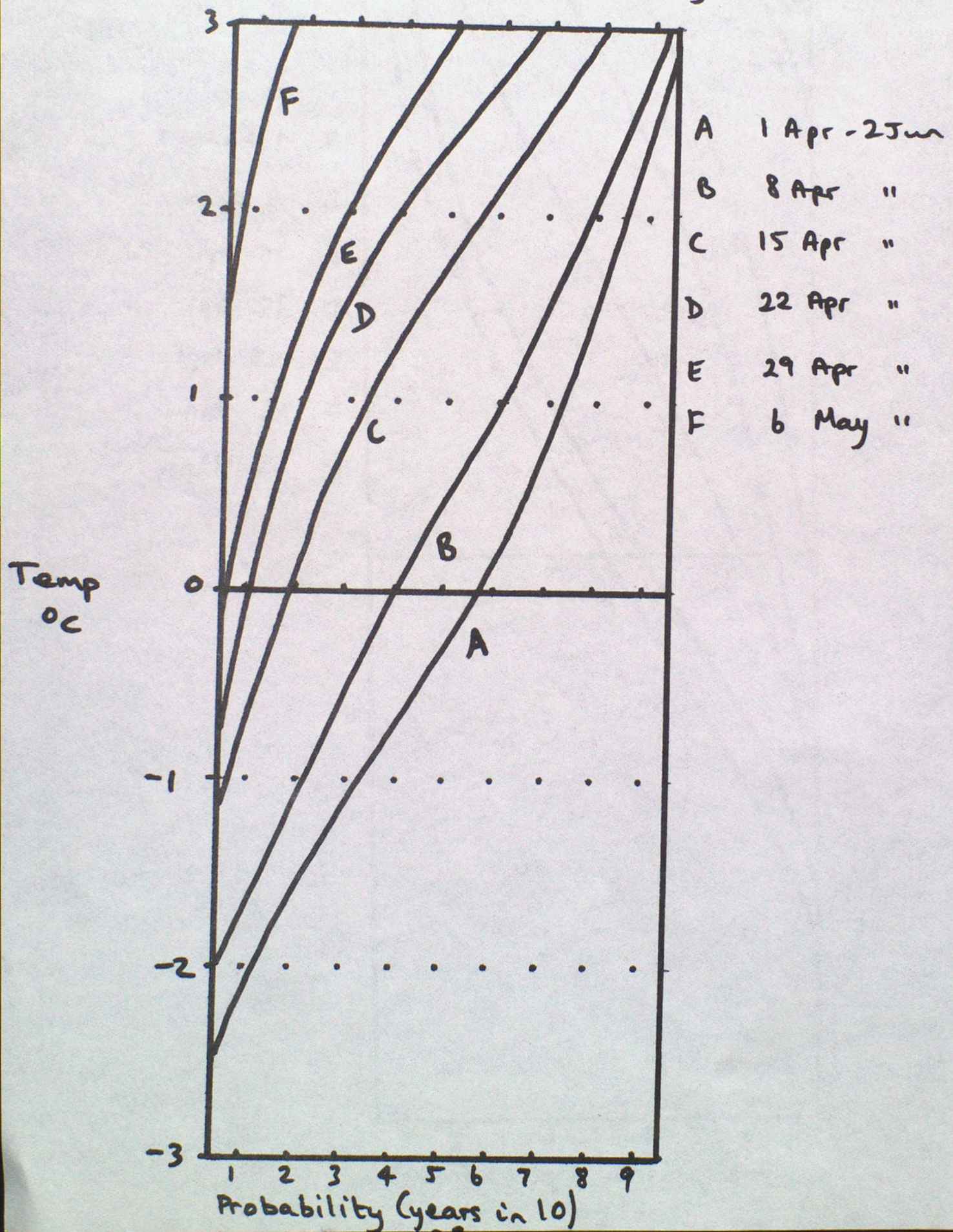
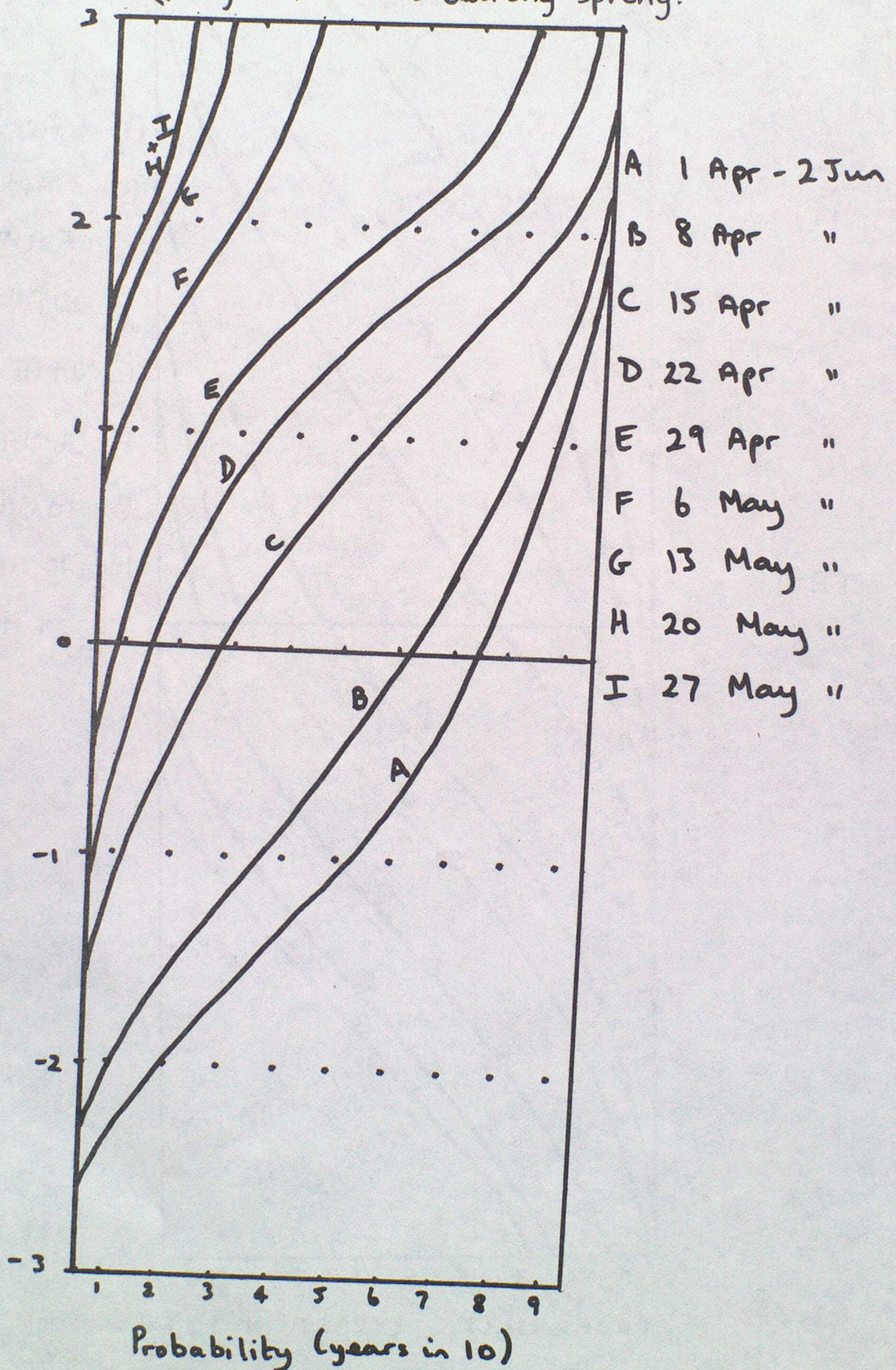


Fig. 18

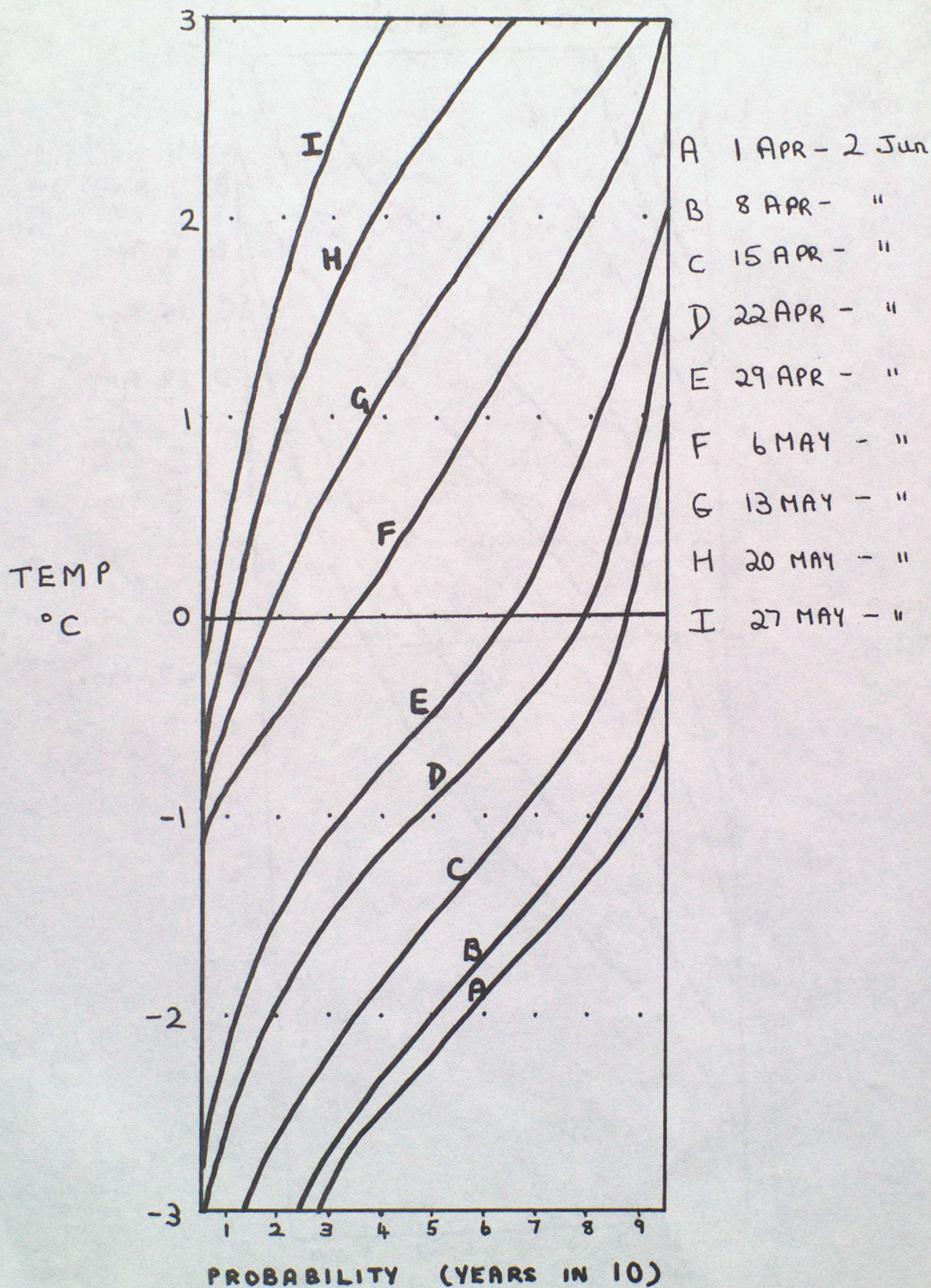
HEATHROW 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



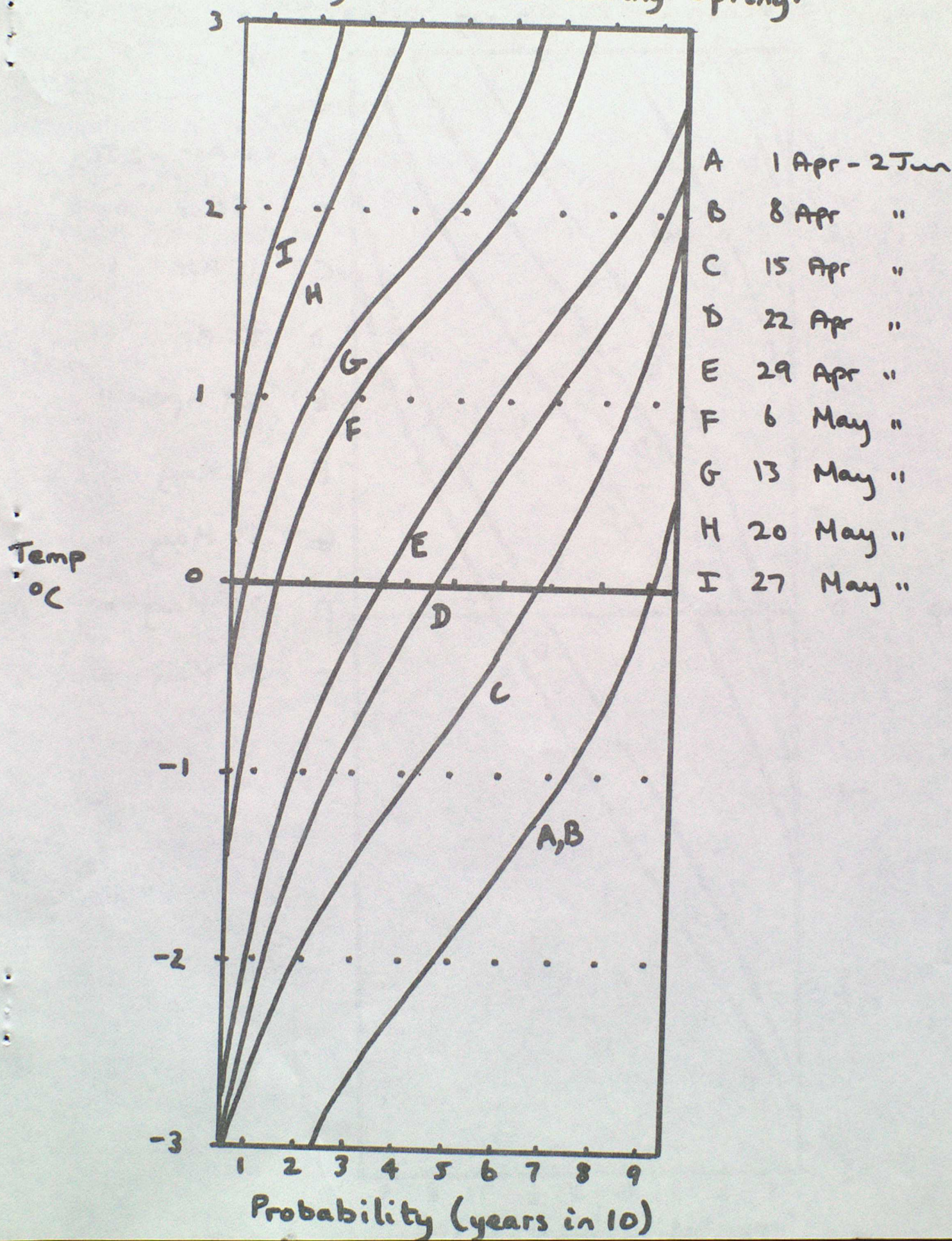
HURLEY (1959-79)

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING



LECKFORD 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.



LITTLEHAMPTON 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.

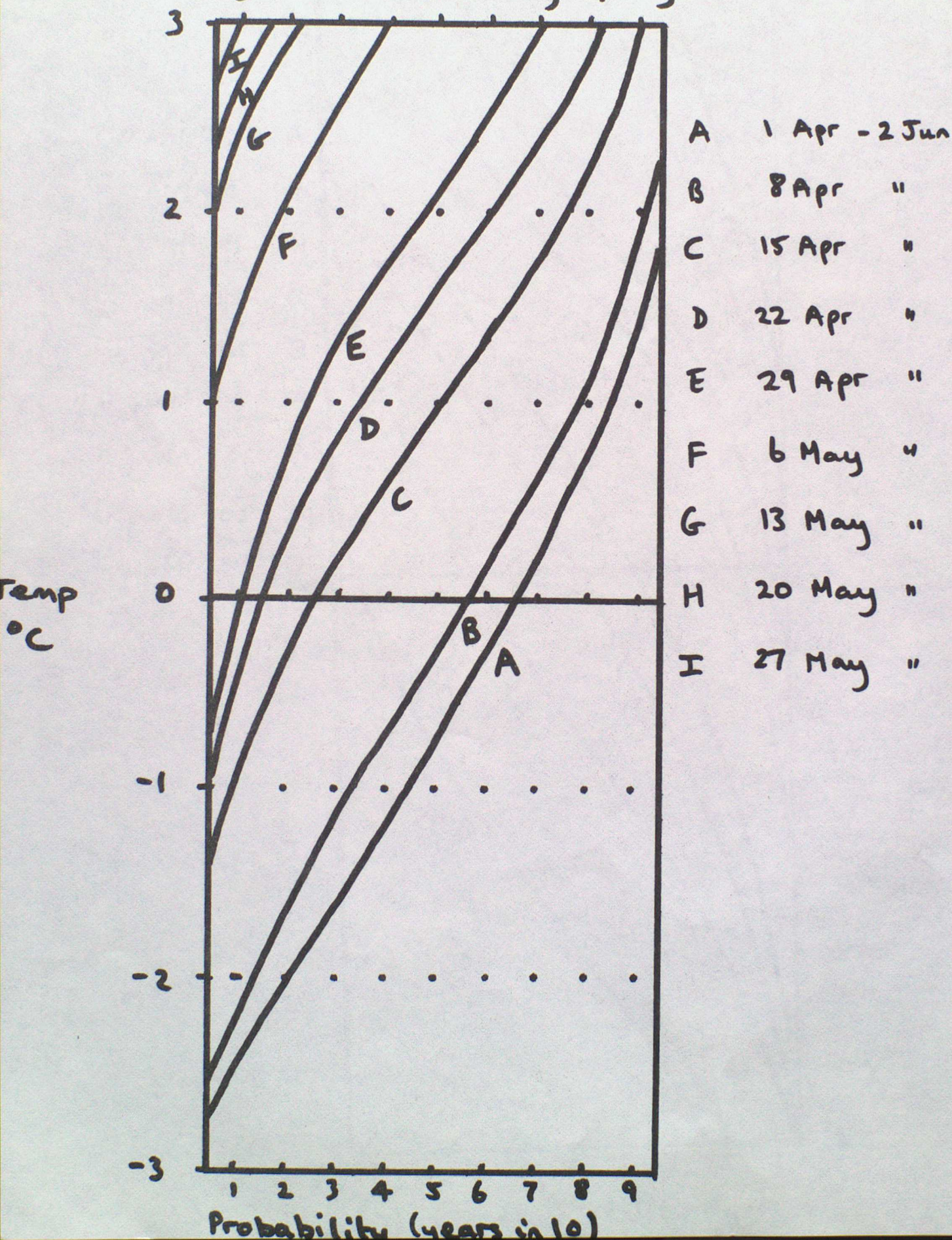
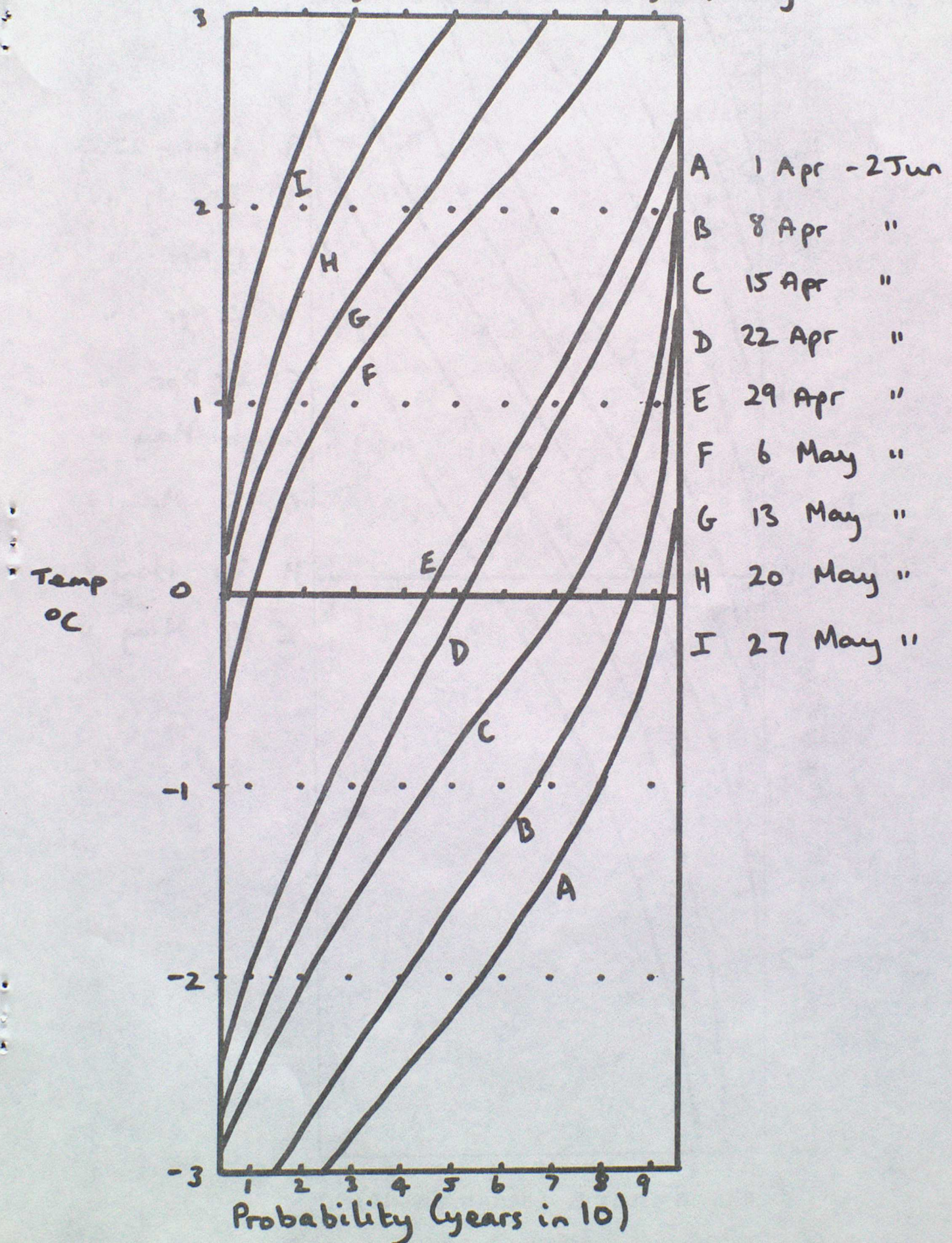


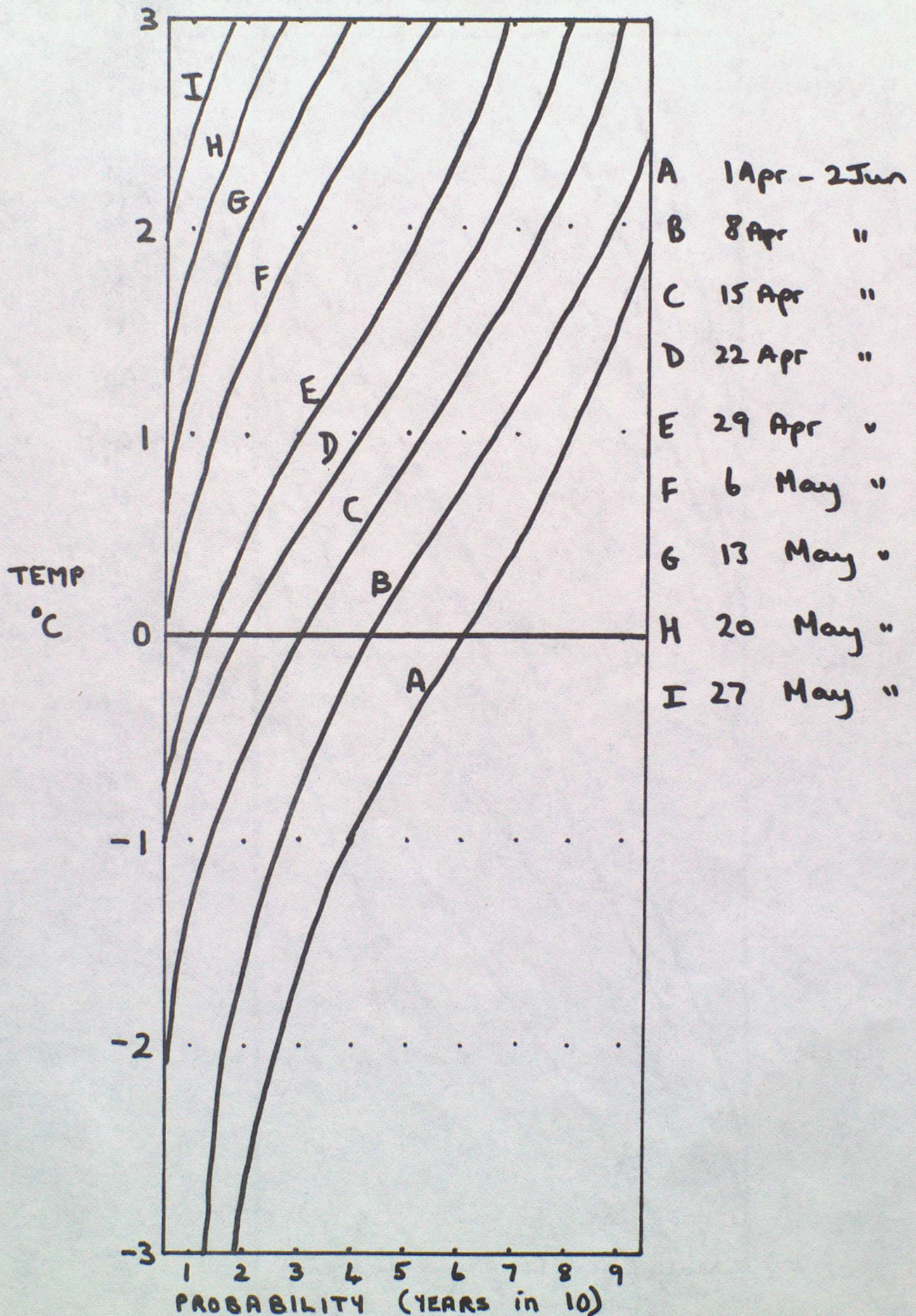
Fig. 22

LONG - SUTTON 1959-79

Probability of at least one air temperature
 $\leq$ given limits during Spring.

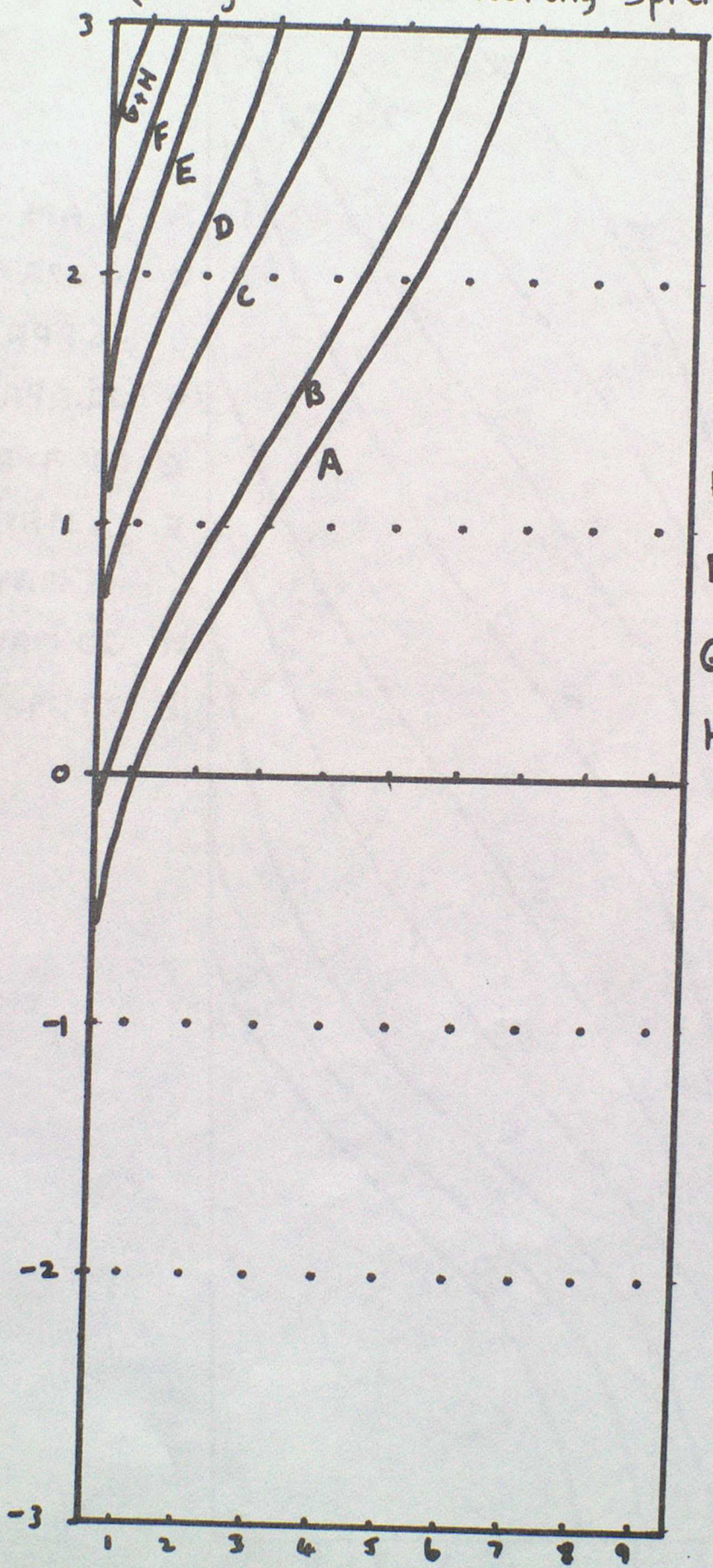


PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING.



MARGATE 1959-79

Probability of at least one air temperature
 given limits during Spring.

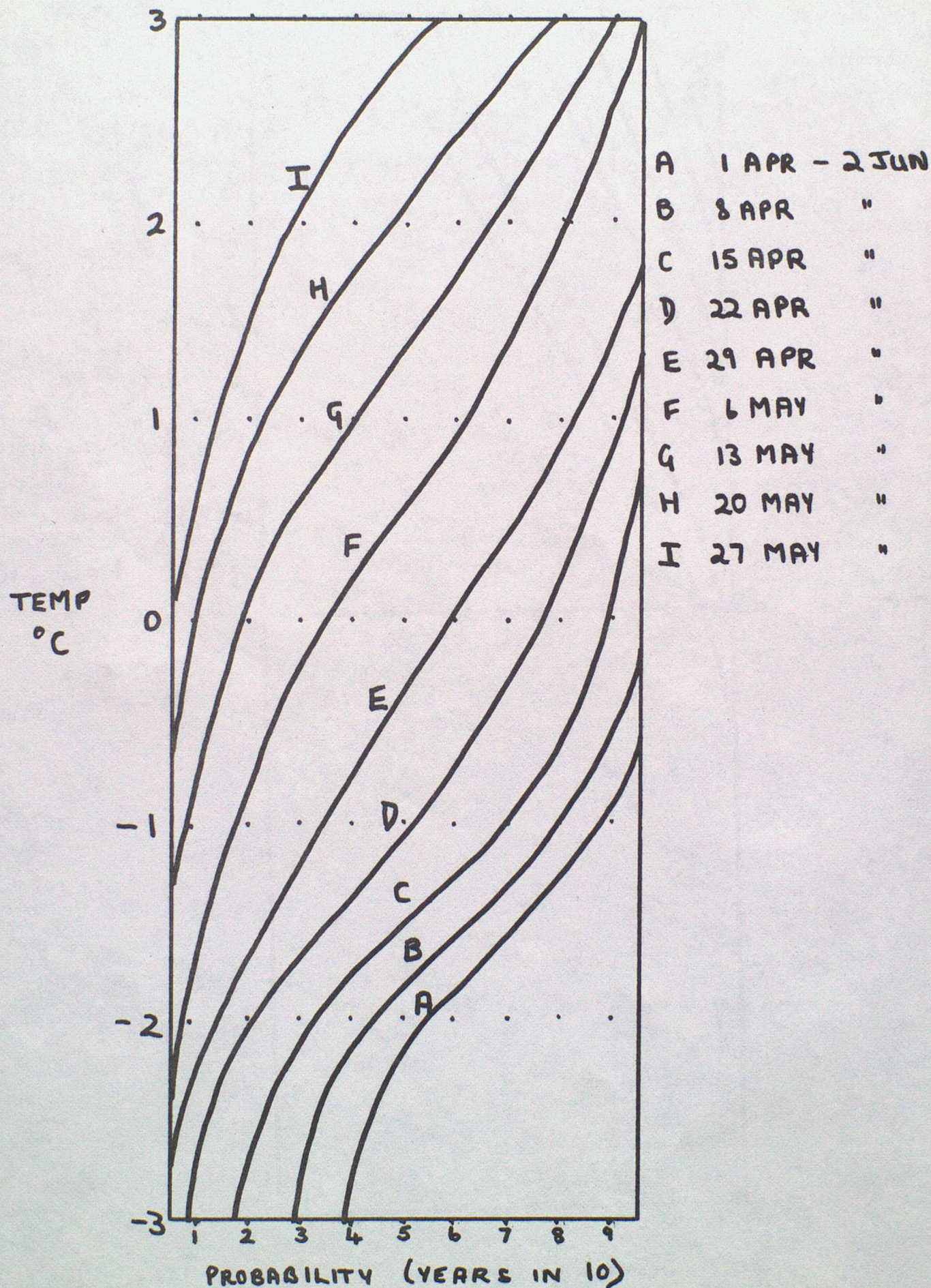


- A 1 Apr - 2 Jun
- B 8 Apr "
- C 15 Apr "
- D 22 Apr "
- E 29 Apr "
- F 6 May "
- G 13 May "
- H 20 May "

Probability (years in 10)

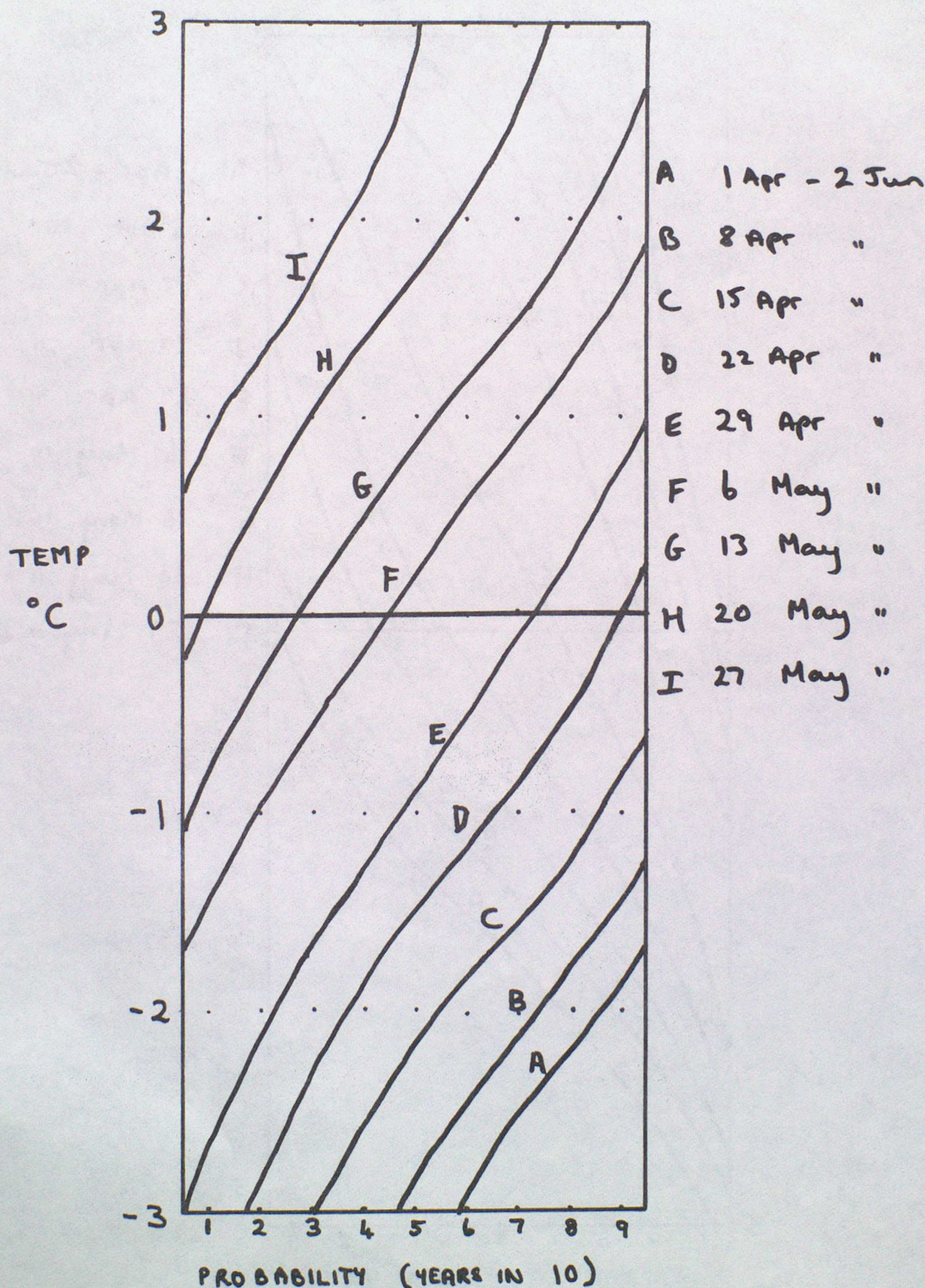
MARTYR WORTHY (1959-79)

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING



NORTH HEATH (1969-77)

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING



SHINFIELD (1959-77)

Fig. 27

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE

$\leq$ GIVEN LIMITS DURING SPRING

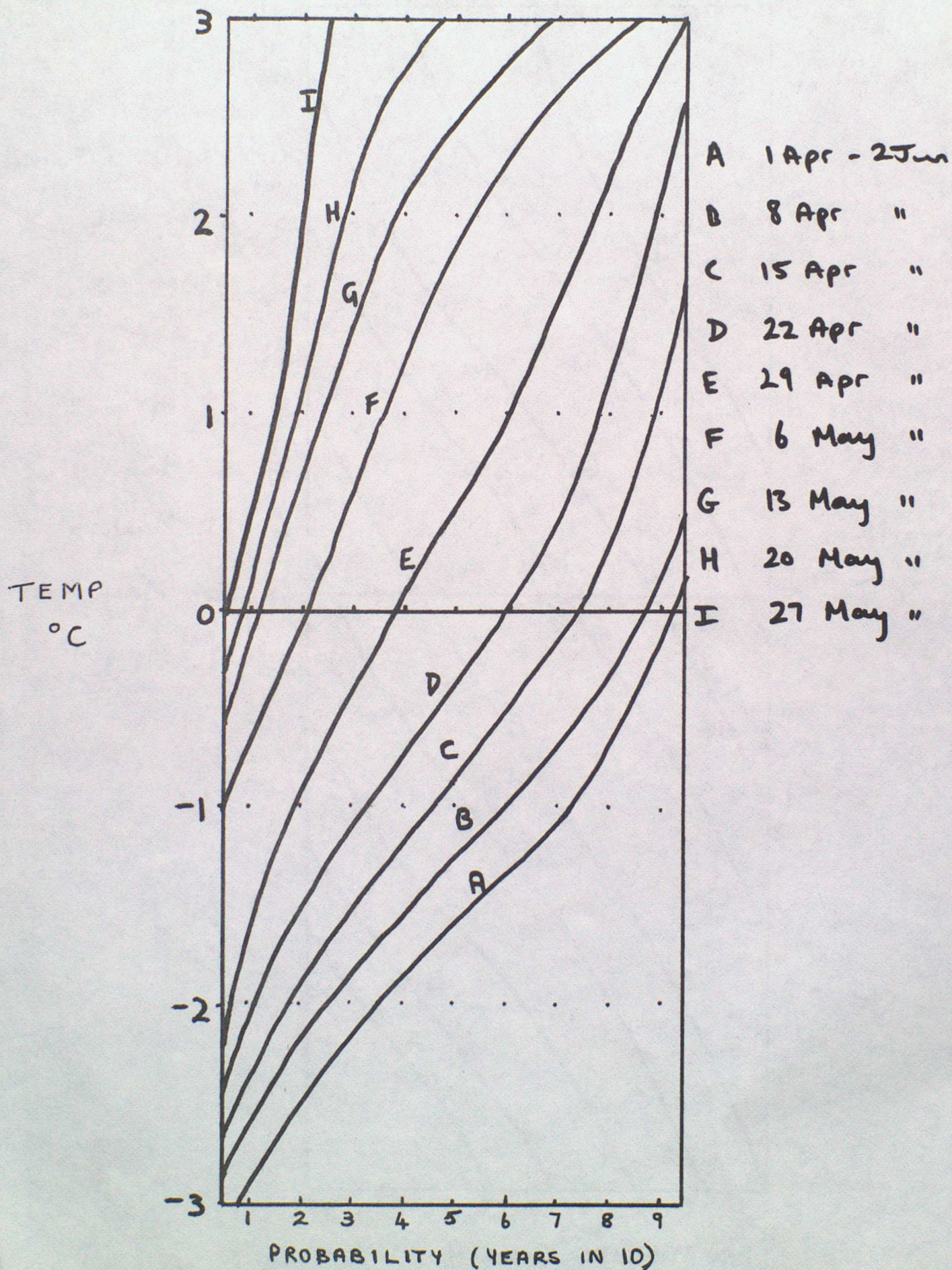
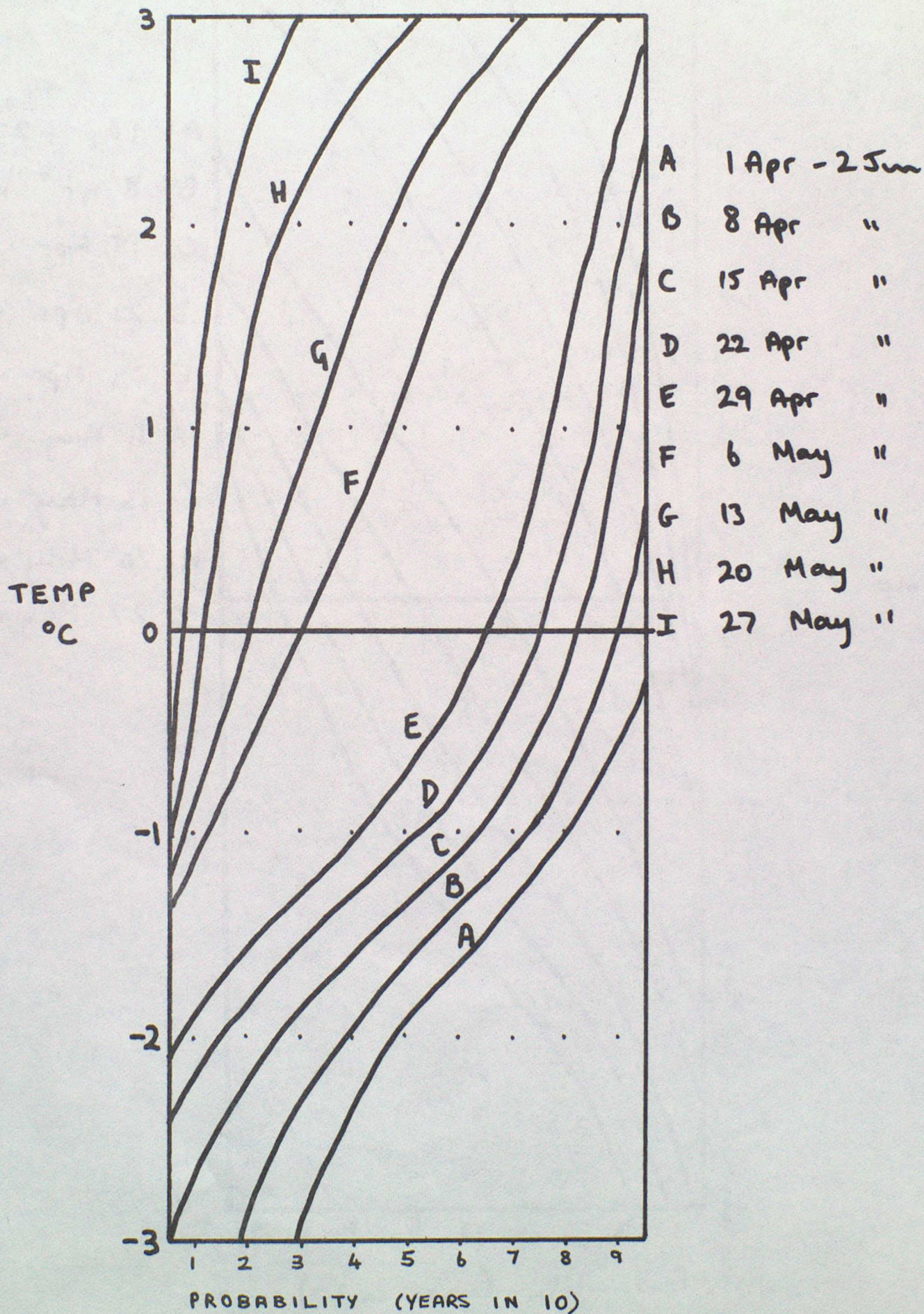


Fig. 28

WISLEY (1959-79)

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING

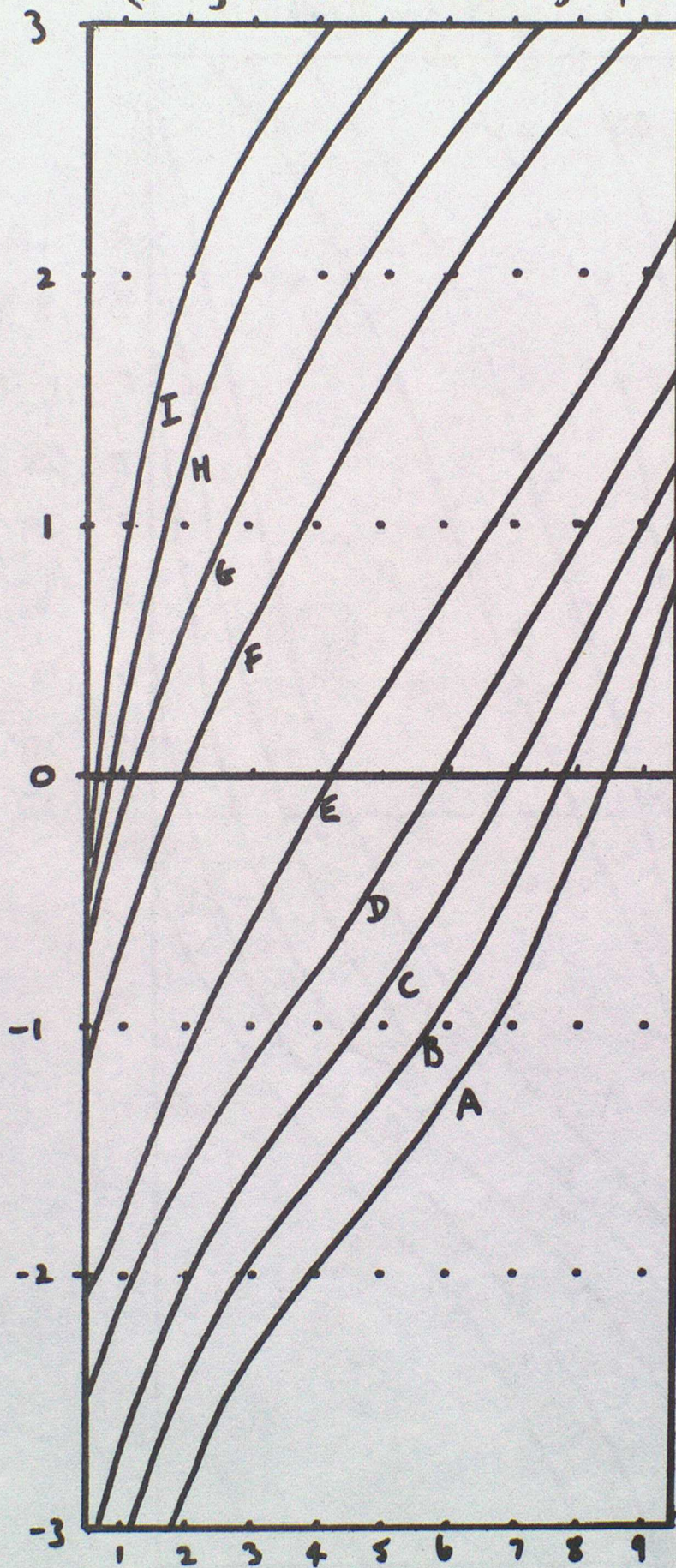


WYE

1959-77

Fig. 29

Probability of at Least one air temperature
 $\leq$ given limits during Spring



A 1 Apr - 2 Jun

B 8 Apr "

C 15 Apr "

D 22 Apr "

E 29 Apr "

F 6 May "

G 13 May "

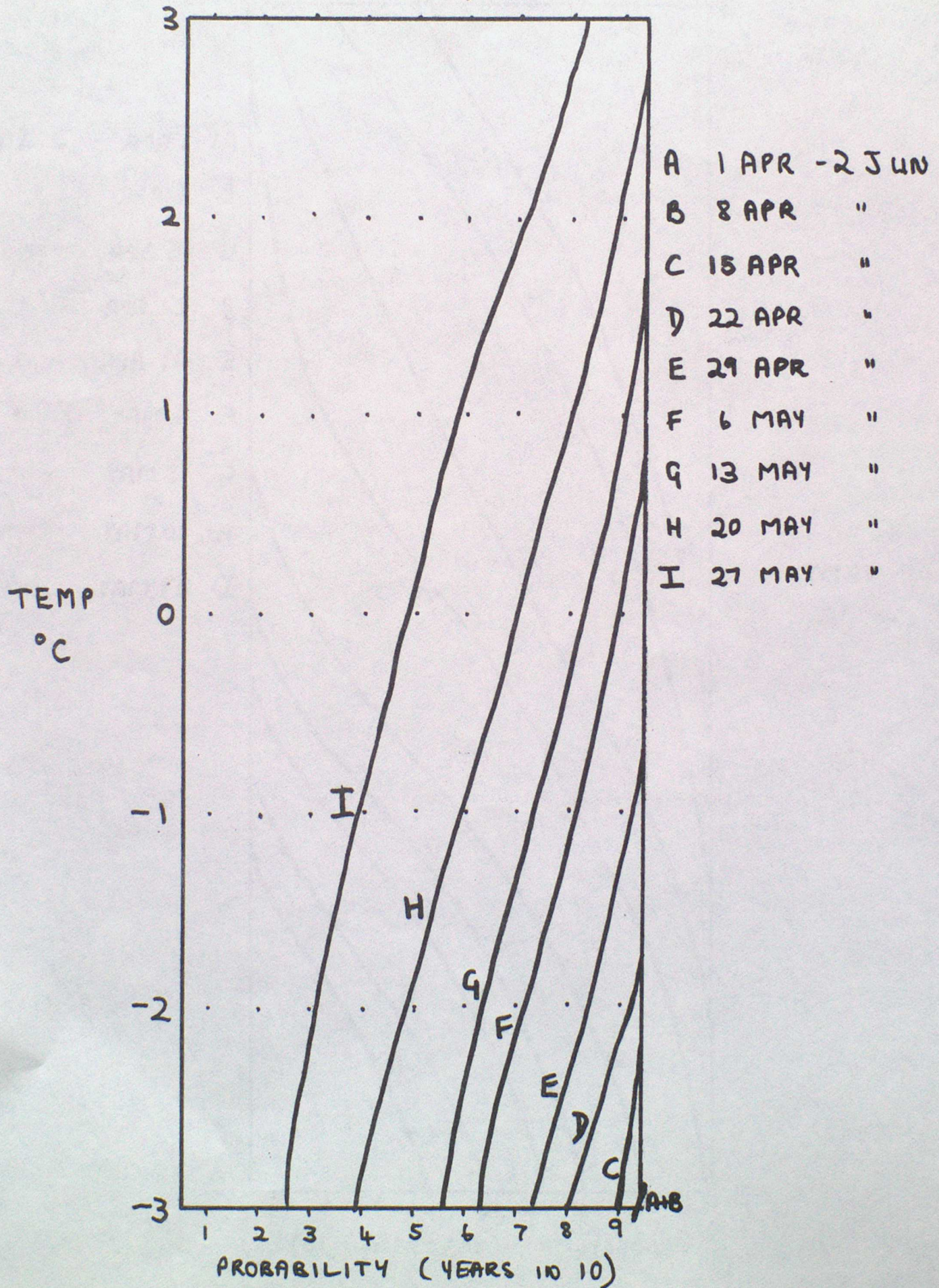
H 20 May "

I 27 May "

Fig. 30

SANTON DOWNHAM (1959-79*)

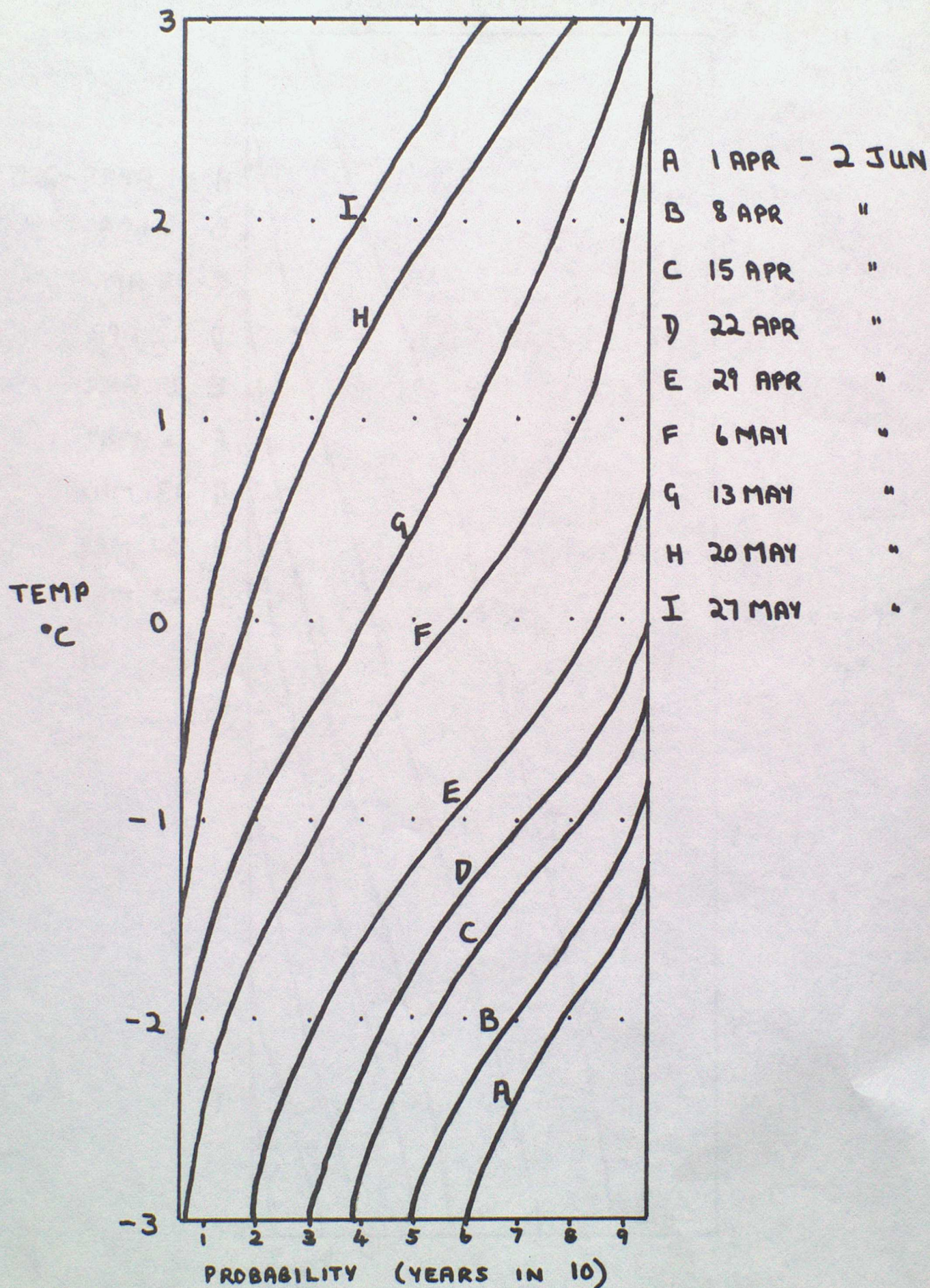
PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING



STRATFORD-UPON-AVON (1959-79)

FIG. 31.

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING



PENZANCE (1959-79)

PROBABILITY OF AT LEAST ONE AIR TEMPERATURE
 $\leq$ GIVEN LIMITS DURING SPRING

